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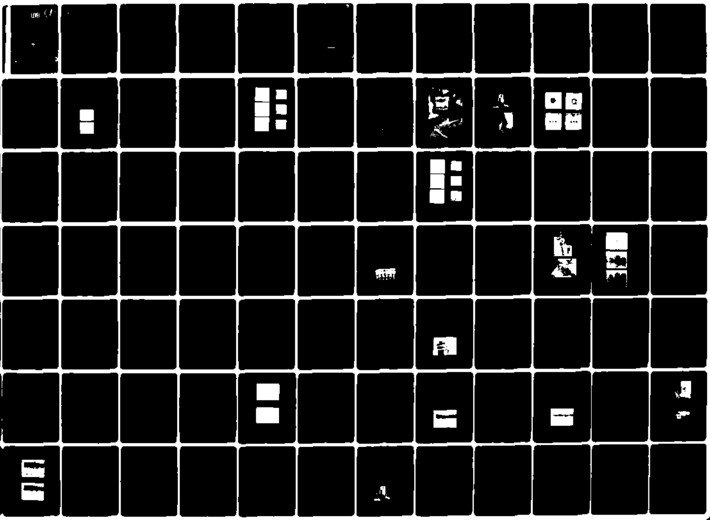

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LEVEL II

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A longstanding problem in radar and electromagnetic scattering measurements is the reconstruction of object shape and detail, i.e. an image, from far field scatter data to be used in object identification and classification. During the period covered by this report we have been able to demonstrate in a feasibility study the first reconstruction of a 3-D image of a perfectly reflecting object from its wave-vector diversity (multifrequency and multi-aspect) scatter data making use of a new *Weighted Fourier Domain Projection*

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Theorem (*WFDPT*) and establish a relationship between holography with wavelength diversity and inverse scattering. Coherent wave vector diversity radar techniques are used to access a finite volume of the 3-D Fourier space (also known as reciprocal space or $\bar{p}$-space) of the scattering object. The WFDPT permits the use of hybrid (digital/optical) computing that enables the retrieval and display of 3-D image information in parallel slices or cross-sectional outlines. The major attributes of this approach as compared to totally digital computing are its potential for displaying a true 3-D image in real-time. Wave-vector diversity methods appear suitable for the imaging of two classes of practical objects namely non-dispersive perfectly reflecting objects of the type often encountered in radar (and sonar) and semitransparent weakly scattering objects such as certain ultrasound and light scattering objects encountered in biology and medicine. The method has several unique characteristics. It furnishes true super-resolution, i.e. resolution exceeding the classical Rayliegh Limit of the available recording aperture, in this case a highly thinned (widely dispersed) broad-band coherent receiver array. True super-resolution is achieved because of an inherent aperture synthesis due to frequency diversity (frequency scanning, stepping or comb illumination) and conversion of spectral degrees of freedom into spatial image detail. Accordingly, when applied to the imaging of a dispersive object, a *target signature* rather than a geometrical image should be expected. Such a target signature could still be useful in object identification and classification since it contains information pertaining to the material composition of the object intermixed with geometrical image detail. The use of frequency diversity was found to lead to a unipolar impulse response. This is very useful in suppressing coherent noise (speckle) which is known to be the major drawback of coherent imaging.

Preliminary work on 3-D image display has yielded encouraging results on 3-D display from a series of weighted projection holograms of various slices of a test object. The projection holograms were viewed in rapid succession using the virtual Fourier transform.

To identify optimal and practical approaches to wave-vector diversity data acquisition a unique microwave measurement system has been assembled, installed and tested in our anechoic chamber facility. The system was used also in the study of TDR (target derived reference) methods in which a reference for phase measurement can be furnished by the scattering object eliminating thus the need for costly local oscillator distribution networks and eliminating at the same time undesirable range phase ambiguities from the collected data. The measurement facility is computer aided furnishing thereby semi-automatic control of object positioning or orientation, frequency stepping, data acquisition and storage, and final data correction and analysis. A high resolution CRT display enables the display of *weighted projection holograms* computed from the $\bar{p}$-space data making use of the WFDPT. Preliminary results of this measurement system capabilities included in this report confirm its tremendous versatility. At this stage, the program strongly suggests the practical feasibility of a new generation of cost effective, real-time, super-resolving 3-D imaging radars that can because of their 3-D image slicing characteristic be appropriately referred to as *Tomographic Radars* (Tomos=slice in Greek).

Finally, a study of 3-D imaging using other forms of broadband radiation such as impulsive, random noise and particularly thermal emission for passive 3-D wavelength diversity imaging has been also initiated.

The findings in this report are those of the authors and are not to be interpreted as the official position of the Air Force Office of Scientific Research or the U.S. Government.

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FINAL REPORT

SUPER RESOLUTION IMAGERY BY FREQUENCY SWEEPING

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N.H. FARHAT AND C. WERNER

HIGH RESOLUTION FREQUENCY SWEPT IMAGING

1. Introduction

The aim of the research work outlined in this final report was the analysis and investigation of methods by which frequency or wavelength diversity techniques can be employed to impart to a highly thinned, and therefore cost-effective, longwave (microwave or ultrasound) imaging aperture resolution capabilities better than its monochromatic classical (Rayligh) limit achieving thereby super-resolution by means of frequency synthesized apertures. This approach to longwave imaging gains practical significance when one considers the current highly developed state of the art of broadband microwave gear suitable for use in a new generation of cost-effective high resolution microwave imaging radars utilizing frequency diversity techniques.

It is well known that the development of longwave holographic imaging systems possessing resolution and image quality approaching those of optical systems is hampered by three factors: (a) prohibitive cost and size of longwave imaging apertures, (b) rapid deterioration of longitudinal resolution with range, (c) inability to view a 3-D image as with optical Fresnel holograms because of a wavelength scaling problem and (d) degradion of image quality by speckle or coherent noise because of the low numerical apertures attainable with present techniques. For example, a longwave imaging aperture operating at a wavelength of 3 cm should be about 3 km in size in order to achieve image resolution comparable to an ordinary photographic camera. In addition to inconvenient size, the cost of filling such a large aperture with suitable coherent sensors is clearly prohibitive. Furthermore, recall that in conventional longwave holography when optical image retrieval is utilized, it is necessary to store the longwave hologram data (fringe pattern) in an optical transparency suitable for processing on the optical bench using laser light. In order to avoid longitudinal distortion* of the reconstructed image, the size of the optical hologram replica must be m ($=\lambda$long/λlaser) times smaller than the longwave recording aperture. For the example cited earlier, this means an optical hologram replica of less than a millimeter in size. It is certainly not possible to view a virtual 3-D image through such a minute hologram even with optical aids since these tend to introduce their own longitudinal distortion. As a result, longwave holographers have long learned to forgo 3-D imagery and settled instead for 2-D imagery obtained by projecting the reconstructed real image on a screen. This permits lowering of the reduction factor m and consequently relaxing the resolution requirements of the photographic film which allows in turn the use of highly convenient Polaroid transparency film for preparation of the optical hologram replica. Because of the small size (measured in wavelength) of longwave apertures attainable in practice and the above methods of viewing the real image, speckle noise is always present leading to degration in image quality.

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* Longitudinal distortion causes for example the image of a sphere to appear elongated in the range direction like a very long ellipsoid.

In this report we summarize the main results of our investigation under this grant. Our findings show that frequency diversity techniques not only circumvent the limitations discussed above but provide a means of viewing true 3-D images of distant objects such as satellites and aircraft. It is worthwhile to point out that our studies of wave-vector diversity imaging (or frequency swept imaging) were motivated to some extent by evidence of super-resolved "imaging" capabilities in the dolphin and the bat which are known to use frequency swept (chirp) signals in their "sonar" to discern small objects in their environment.

2. Summary of Important Results

The main findings of the study, details of which are given in the appendices and our publications (see list of publications), are outlined next.

(a) Wave-vector diversity (multifrequency and multiaspect) techniques can be used to enhance the amount of object information collected by a broadband coherent aperture deployed in the far field of the scattering object. Thus the data collected by a highly thinned array of coherent receivers intercepting the wavefield scattered from a distant 3-D reflecting object, as the frequency of its illumination (and/or its direction of incidence) are changed (see Fig. 1-a for example), can be stored as a 3-D data manifold in $\bar{p}$-space (Fig. 2) from which an image of the object can be retrieved by means of a 3-D Fourier Transform. The size and shape of the 3-D data manifold, and therefore the resolution, depend on the relative positions of the object, the transmitter (illuminator), and the receiving array and on the spectral width of the illumination utilized.

(b) The data collected must be corrected for a quadratic phase factor F (caused by the unequal distances between the object and the receiving stations forming the widely dispersed imaging array) before it is stored in a 3-D manifold in $\bar{p}$-space and an undistorted image of the 3-D reflecting object reconstructed through the 3-D Fourier transform operation. A bothersome range-azimuth ambiguity is also avoided through elimination of this quadratic phase term.

The most promising methods for data acquisition and correction is that which utilizes a target derived reference (TDR) at the synchronous detectors of the various receivers to correct for the unequal phase shifts or propagation time delays from the object to each receiver. In this approach the data furnished by the various receivers of the recording array is free of the undesired factor F. Therefore no additional processing by a computer will be necessary before filing the data at the appropriate locations in $\bar{p}$-space. The TDR method has several advantages which include:

(i) Elimination of the need for a costly and unreliable central local oscillator distribution network.

(ii) Because TDR results in a recording configuration similar to that of a lensless Fourier Transform hologram, the resolution requirements from the recording device are greatly relaxed*.

*A. Macovski, "Hologram Information Capacity", J. Opt. Soc. Am., Vol. 60, Jan. 1970, pp. 21-29.

In longwave holography this fact is translated into a significant reduction of the number of receiving elements in the recording aperture. In addition the use of TDR allows us to place all the resolving power of the recording aperture on the target. This means that high resolution images of distant isolated targets should be feasible with array apertures consisting of tens of elements. The ability to synthesize a 2-D receiving aperture with a Wells array† consisting of two orthogonal linear arrays one of transmitters and the other of receivers provides further means of reducing the number of stations needed for data acquisition without sacrifice in resolution. A frequency swept Wells array of 10 transmitters and 10 receivers using a (2-4) GHz sweep should be able to easily furnish 10^4 3-D distinguishable resolution cells on the target which is more than sufficient for discerning the scattering centers on practical targets.

(iv) Greater immunity to phase fluctuations arising from turbulance and inhomogenieties in the propagation medium because both the reference and imaging signals arriving at each receiving element of the aperture travel roughly over the same path.

(v) TDR eliminates the range azimuth ambiguity and excessive bandwidth problems that arise in fast frequency swept imaging when the reference signal for the array aperture is distributed instead from the illumination source or a centrally located local oscillator phase locked to it.

Two TDR methods have been considered to some extent in our work to date. In one method which we term LFTDR (*Low Frequency Target Derived Reference*), the object is assumed to be illuminated simultaneously with a high frequency imaging signal and a low frequency signal that is a subharmonic of the illuminating frequency. The subharmonic reference frequency ω_r is chosen such that $k_r \ell << 1$, ℓ being the maximum linear dimension of the object and $k_r = \omega_r / c$, c being the velocity of light. This places scattering from the object in the Rayliegh region where the object behaves as point scatterer with zero phase contribution. The far field phase of the reference signal at any receiver is therefore entirely due to propagation between a reference point formed at the object to the receiver. A method for measuring this reference signal phase and using it to correct the imaging signal phase due to propagation has been proposed by Porter* and analyzed for a one-dimensional object geometry. The reference signal phase and the imaging signal phase are measured separately at each receiving station with the aid of two receivers whose local oscillators (L.O)'s, one at the reference frequency and one at the imaging frequency, are phase-locked only to each other and not to a central local oscillator as would be the case were we to use a conventional receiver array. Phase locking of the two LO's can be accomplished by simply making the imaging L.O a harmonic of the

†C.N. Nilsen and D.N. Swingler, "Quasi-Real-Time Inertialess Microwave Holography", Proc. IEEE (Letters), Vol. 65, March 1975, pp. 491-492.
*R.P. Porter, "A Radar Imaging System Using the Object as Reference", Proc. IEEE (Letters), Vol. 59, Feb. 1971, pp. 307-308.

reference L.O. This would eliminate the difficulties encountered in the implementation of large or giant thinned coherent receiving arrays of the type required here, namely the distribution of a central local oscillator signal. A great reduction in cost and effort associated with installation of a central L.O. distribution network can thus be achieved. This cost reduction should be compared however with the cost of implementing a LFTDR. Because of the large difference between the high frequency imaging frequencies and the low frequency reference frequency required for the high resolution imaging of practical objects, the same microwave gear can not be used for both frequencies. This could increase system cost. In addition since the measured reference phase must be multiplied by a factor β equal to the ratio of the imaging to the reference frequency before being used as a reference phase in the imaging signal measurement, any errors in the reference phase measurement will also be amplified by this ratio. The precision of the reference phase measurement and phase error analysis are important and will have therefore to be examined further.

Another TDR methods which we call the *Frequency Displaced Target Derived Reference* (FDTDR) also shows promise. In this method, the analytical details of which are outlined in appendix I, the object is illuminated simultaneously during the sweep with two phase locked imaging frequencies ω_1 and $\omega_2 = \omega_1 + \Delta\omega$, $\Delta\omega$ being a small incremental frequency. This can be realized also by single side band modulation of the swept signal or by phase locking two sweep oscillators. Measurement of the differential phase between the signals scattered from the target at these frequencies yields $\frac{\Delta\omega}{c}(R_T + R_R)$, R_T being the distance from the transmitter to the object and R_R being the distance from the object to the receiver. Multiplication of this phase by $\omega_1/\Delta\omega$ yields the phase factor F at frequency ω_1 which would be used to correct the phase measured at ω_1. At first look this method would appear to still require a reference local oscillator. This however is not so since the procedure outlined above need not involve explicit phase measurements and multiplications. For example by mixing the two received signals at ω_1 and $\omega_1 + \Delta\omega$ in a square law detector at each receiver a beat signal at frequency $\Delta\omega$ is derived whose phase is equal to $\frac{\Delta\omega}{c}(R_R + R_T)$. The phase shift of this signal due to the object is effectively zero because the wavelength at $\Delta\omega$ is much larger than the object extent making it behave effectively as a point scatterer. Harmonic mixing of the signal ω_1 received at each receiver with this beat signal should yield the corrected $\bar{p}$-space data at ω_1. Because of the small difference $\Delta\omega$ between the two frequencies ω_1 and ω_2 utilized, the effect of phase errors due to system and atmospheric propagation could be more completely cancelled in this method than in the low frequency TDR methods. The small difference $\Delta\omega$ means also that unlike the LFTDR case the same microwave gear (antennas, transmission lines and other microwave circuit components) can be utilized in the handling of the reference and imaging signals. A variation of the TDR technique involving double side-band modulation is also possible and appears to be more simple to implement than the single side-band method.

(c) Because in addition to being dependent on geometry, the dimensions of the 3-D data in $\bar{p}$-space shown in Fig. 2 are dependent on the spectral range of the illumination, super-resolution (i.e. resolution beyond the classical limit of the available physical aperture) is achieved. This aperture synthesis by wave-vector or frequency diversity helps cut down array cost (since a thinned array can be used to frequency synthesize a large array with higher filling factor).

(d) *Fourier Domain Projection Theorems* (see appendixes II and III for details) enable the generation of two dimensional holograms from projections (or weighted projections) of the corrected $\bar{p}$-space 3-D data manifold of Fig. 2 permitting thereby optical image retrieval of the 3-D object in slices parallel to the projection plane one at a time. For example, Fig. 1-b shows the projection hologram for the $\bar{p}$-space data obtained in a computer simulation of the arrangement shown in Fig. 1-a. The central cross-sectional outline of the object (the two 1 m diameter reflecting spheres of Fig. 1-a) retrieved from this projection hologram by means of a 2-D Fourier transform carried out on the optical bench is shown in Fig. 1-c. A similar example is shown in Figs. 3 and 4. Figure 3 shows a second test object consisting of 3-D distribution of a set of 8 point scatterers with locations and spacings given in the Figure. Figure 4 shows the projection holograms corresponding to the three slices of the object containing the point scatterers and the image retrieved from each. The sweep width in this example, as in the previous example, was (2-4) GHz however the number of receivers in the recording array has been reduced from 50 to 16. These computer simulations demonstrate that a 3-D (lateral and longitudinal) resolution of the order of twenty centimeters* is easily achieved with a frequency sweep covering only (2-4) GHz using a broad-band array of 16 receivers and one transmitter. Wider-spectral windows should yield better resolution. It is worthwhile to note in this respect that commercial microwave sweepers and synthesizers are available with a spectral coverage of (.1-25) GHz indicating a potential for practical resolutions of the order of possibility few centimeters with cost-effective broad-band apertures consisting of tens of receivers operating with one central illuminator.

(e) The viewing or the display of a true 3-D image of the various slices or cross-sectional outlines should be possible by reconstruction of the various projection holograms in rapid succession while projecting the reconstructed real images of the corresponding slices on a rapidly moving projection screen. The screen would be displaced rapidly (together with the Fourier transforming lens) on the optical bench in the axial directions by small amounts proportional to the distances between the various slices. In another approach we have found that the 2-D *virtual Fourier transform* of a projection hologram can be carried out by simply viewing (with the unaided eye) a transparency containing an array of reduced replicas of the projection hologram arranged side-by-side with a point source. The image retrieved in this fashion would lie in the plane of the point source. This approach has the potential for 3-D display by viewing the virtual images retrieved from a series of projection holograms corresponding to different slices or cross-sectional outlines

*This means 10^3 distinguishable 3-D resolution cells in the $(2 \times 2 \times 2)m^3$ volume of the assumed object.

of the object passed in front of the eye in rapid succession while moving the reconstruction point source axially back and forth at a suitable rate of incremental axial displacements. A proposed electro-optical scheme that permits carrying out this procedure in real-time using a rapidly recyclable spatial light modulator (SLM) operating in a reflection mode is shown in Fig. 5. The computer, the high resolution CRT and the projection optics are used to project reduced noncoherent images of the various projection holograms in rapid succession on the SLM while the axial position of the reconstruction point sources is altered rapidly also under computer control. The point source need not be derived from a laser in order to yield an image but could also be a miniature "grain of wheat" light bulb. Details of this task are found in Appendix III.

(f) As seen in (e), unlike monochromatic longwave holographic imaging, there is no specific scaling requirements imposed on the projection holograms in order to avoid longitudinal distortion in the optical reconstruction circumventing thus the wavelength scaling problem.

(g) Because of the broad spectral extent of the illumination used and ability to display the reconstructed image in separate slices, speckle or coherent noise, which is known to plague coherent imaging systems, is suppressed making the system behave in as far as image noise is concerned like a noncoherent imaging system but at the same time enjoy the superior detection characteristics associated with synchroneous detection techniques.

(h) The broad-band nature of the imaging process also helps suppress undesirable image detail that could arise from object resonances which could seriously degrade image quality in a monochromatic imaging system.

(i) The data collected at every receiver, represents after correction, essentially the frequency response of the scattering object measured from a different aspect angle. Assuming the scattering process is linear, this frequency response is related to the impulse response of the object by a Fourier transform (see ref. 5 in List of publications). This suggests that impulse illumination can be utilized instead of frequency swept illumination. When this is done,the 3-D data manifold in $\bar{p}$-space may be generated by Fourier transforming the impulse response at each receiver, correcting the data for the Factor F mentioned in (b), and storing the result in the appropriate $\bar{p}$-space locations for each receiver. The resulting $\bar{p}$-space volume accessed in this fashion can then be employed as described earlier to yield 3-D image information. Impulse illumination is desirable in certain instances of rapid target motion but may be more difficult to implement than frequency swept illumination. Since the impulse reponse of a time invariant linear system can also be deduced from white noise excitation and corellation of the output response with the input as described elsewhere in more detail (see 5 in list of publications), it follows that the techniques described in this report for coherent broadband radiation should be equally applicable with minor signal processing modification to noise-like broadband

radiation including passive black-body radiation.

(j) Experimental verification for both the principle of frequency diversity imaging and the TDR concept were obtained with the aid of a semi-automated network analyzer configured and installed in a recently refurbished anechoic chamber within the scope of this program(see Figs. 6 and 7). This versatile system is capable of vector (amplitude and phase) measurements of wavefields scattered from test objects situated in the anechoic chamber over any frequency range lying in the (.1-18)GHz range for a variety of polarizations. A test object consisting of two parallel cylinders 25 cm apart each 5 cm in diameter and 50 cm long was mounted on a rotating styrofoam pedestal that is under computer control and illuminated as shown in Fig. 8. The distance from the center of the object to the illuminating parabolic antenna to the left and the receiving horn feeding the network analyzer was 2.5 m. The complex frequency response of this object was measured in the (5-14)GHz range and the data stored for 128 object orientation covering 360°. The stored data was corrected for range-phase with a synthetic TDR generated in the computer and the corrected data displayed and photographed yielding the frequency swept hologram shown in Fig. 9 (c). The image retrieved from this hologram via an optical Fourier transform carried out on the optical bench is shown in Fig. 9 (d). For reasons of comparison a computer simulation of this experiment assuring a (2-18)GHz sweep was performed. The resultant range-phase corrected hologram and the image retrieved from it optically are shown in Fig. 9 (a) and (b). Further detail on this phase of the program were reported in an MSc. thesis made part of this report in Appendix IV. This part of the program is being continued with the aim of further enhancing measurement accuracy and demonstrating imaging of a nonsimple 3-D test object such as a model aircraft utilizing polarization diversity to further enhance image quality.

3. Conclusions.

The primarily analytical and numerical study of frequency diversity imaging performed under this grant demonstrates conclusively the feasibility of a new generation of coherent broadband imaging radars capable of furnishing 3-D image detail of distant target with cost effective giant apertures and efficient digital/optical signal processing.

Future work in this area will focus more on the analysis and identification of optimal methods for data acquisition, processing and 3-D display. The ultimate aim is the generation of design criteria for a prototype system and its assessment in the 3-D imaging of low flying aircraft passing within range of our facilities on route for landing at the Philadelphia Airport.

List of Publications

1. N.H. Farhat, "Frequency Synthesized Imaging Apertures", Proc. 1976, International Optical Computing Conference, IEEE Cat. #76 CH 1100-7C, pp. 19-24.

2. N.H. Farhat, M.S. Chang, J.D. Blackwell and C.K. Chan, "Frequency Swept Imaging of a Strip", Proc. 1976, Ultrasonics Symposium, IEEE Cat. #76 CH 1120-5SU.

3. J.D. Blackwell and N.H. Farhat, "Image Enhancement in Longwave Holography by Electronic Differentiation", Optics Communications, Vol. 20, Jan. 1977, pp. 76-80.

4. C.K. Chan, N.H. Farhat, M.S. Chang and J.D. Blackwell, "New Results in Computer Simulated Frequency Swept Imaging", Proc. IEEE (Letters), Vol. 65, pp. 1214-1215, Aug. 1977.

5. N.H. Farhat, "Principles of Broad-Band Coherent Imaging", J. Opt. Soc. Am., Vol. 67, pp. 1015-1020, Aug. 1977.

6. N.H. Farhat, "Comment on Computer Simulation of Frequency Swept Imaging", Proc. IEEE, Vol. 65, pp. 1223-1226, Aug. 1977.

7. N.H. Farhat, "Comment on a New Imaging Principle", Proc. IEEE (Letters), Vol. 66, pp. 609-700, May 1978.

8. N.H. Farhat, "Microwave Holographic Imaging - Prospects For a Real-Time Camera", SPIE, Vol. 180, *Real-Time Signal Processing II*, (1979).

9. N.H. Farhat and C.K. Chan, "Three-Dimensional Imaging by Wave-Vector Diversity", *Acoustical Imaging*, Vol. 8, A. Metherell (ed.), Plenum Press, New York (1980), pp. 499-515.

10. C.K. Chan and N.H. Farhat, "Frequency Swept Imaging of Three Dimensional Perfectly Reflecting Objects", IEEE Trans. on Antennas and Propagation - Special Issue on Inverse Scattering. (Accepted for publication.)

11. C.K. Chan, "Analytical and Numberical Studies of Frequency Swept Imaging", University of Pennsylvania, Ph.D. Dissertation (1978).

12. N.H. Farhat, "Microwave Holography and Coherent Tomography", (Invited paper). Presented at 1980 IEEE/MTT's International Microwave Symposium, Electromagnetic Dosimetric Imaging. (To be published in special conference proceedings).

Related Publications

1. N.H. Farhat, "New Imaging Principle", Proc. IEEE (Letters), Vol. 64, pp. 379-380, March 1976.

2. N.H. Farhat, T. Dzekov and E. Ledet, "Computer Simulation of Frequency Swept Imaging", Proc. IEEE (Letters), Vol. 64, pp. 1453-1454, Jan. 1977.

3. G. Tricoles and N.H. Farhat, "Microwave Holography: Applications and Techniques", Invited paper, Proc. IEEE, Vol. 65, pp. 108-121, Jan. 1977.

4. M.A. Kujoory and N.H. Farhat, "Microwave Holographic Substraction for Imaging of Buried Objects", Proc. IEEE (Letters), Vol. 66, pp. 94-96, Jan. 1978.

5. M.A. Kujoory and N.H. Farhat, "Format Generation For Double Circular Scanners For Use in Longwave Holography", Acoustical Imaging and Holography, Vol. 1, No. 2, pp. 133-141 (1979).

6. N.H. Farhat and J. Bordogna, "An Electro-Optics and Microwave-Optics Program In Electrical Engineering", IEEE Trans. on Education - Special Issue on Optics Education (accepted for publication).

7. N.H. Farhat, "Holographically Steered Millimeter Wave Antennas", IEEE Trans. on Antennas and Propagation, Vol. AP-28, July 1980, pp. 476-480.

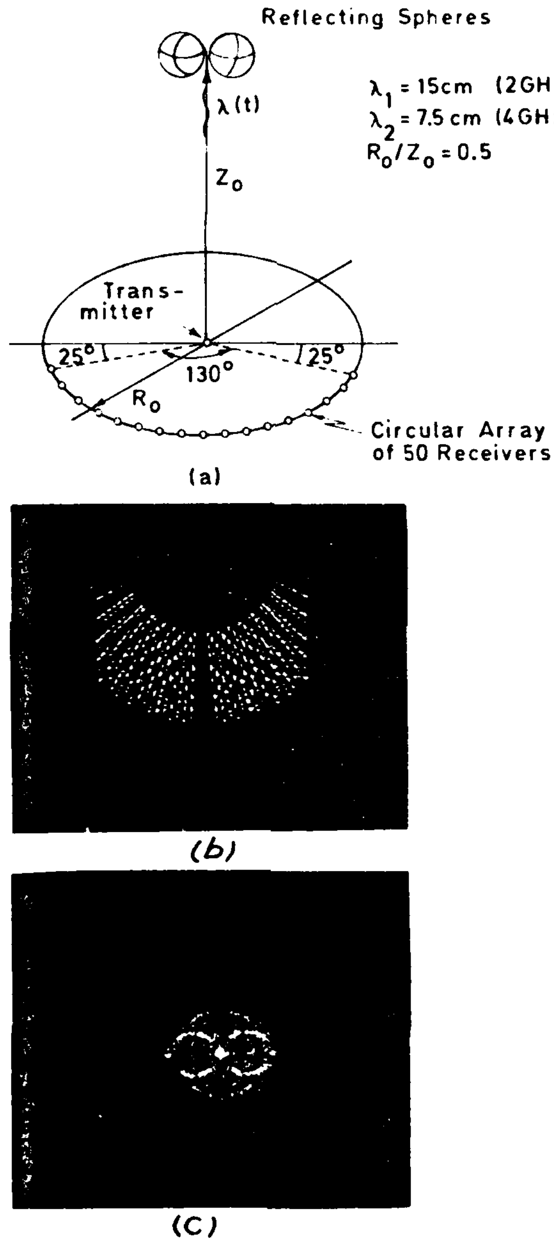


Fig. 1. Computer Simulation of Wave-vector Diversity Imaging, (a) Geometry, (b) Projection Hologram, (c) Retrieved Central Cross-sectional Image.

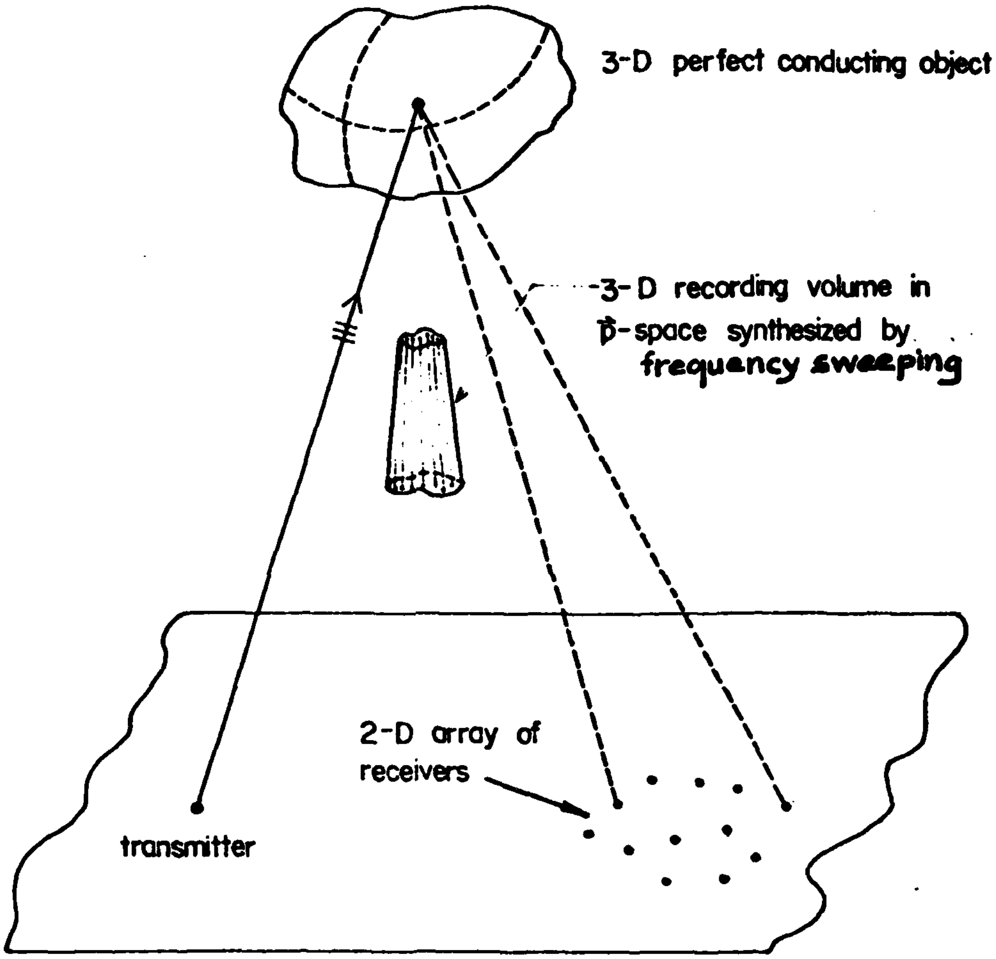


Fig.2 Three dimensional $\vec{p}$-space data generated by frequency sweeping and collected by a 2-D array of receivers.

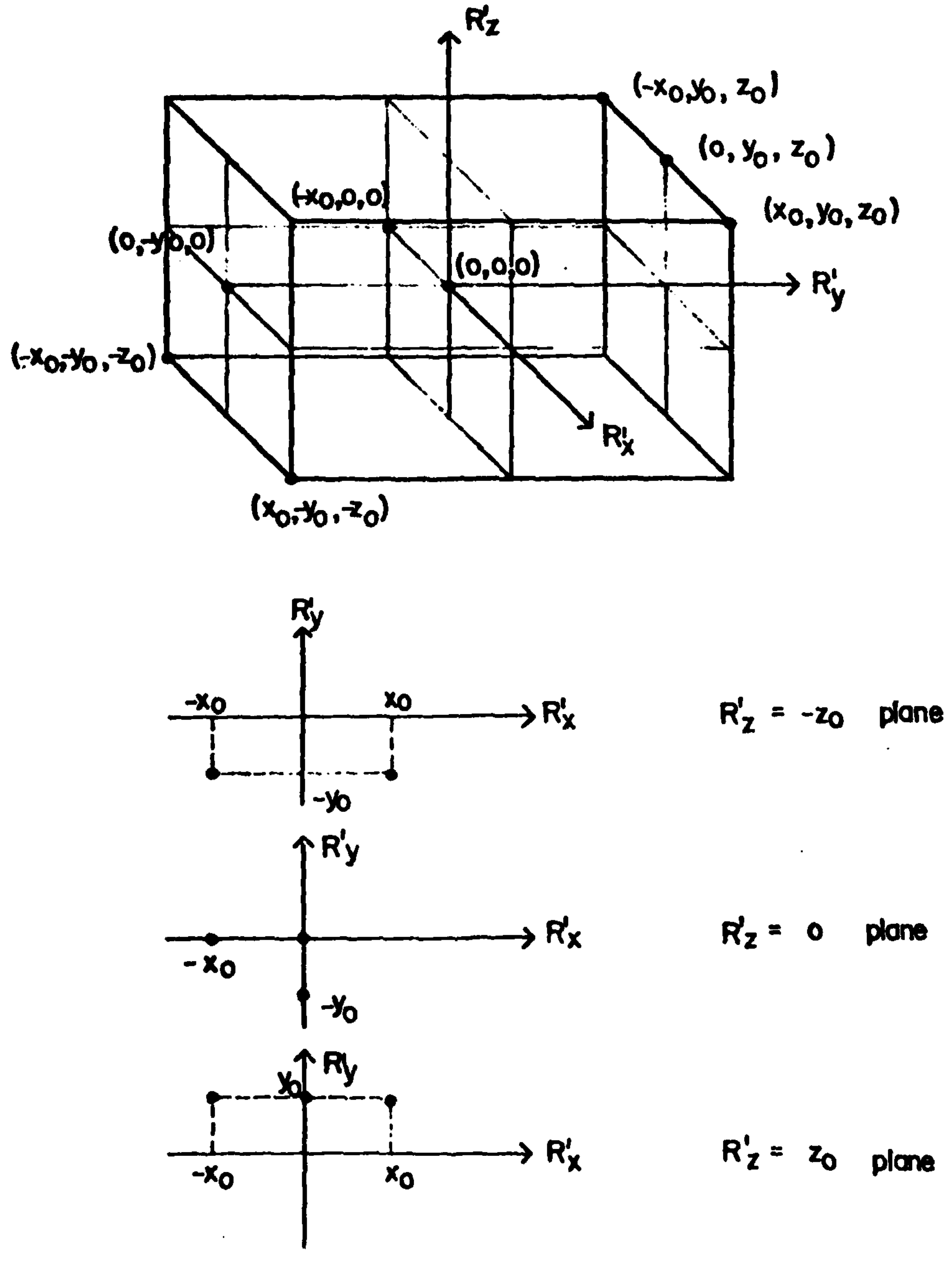


Fig. 3. 3-D object consisting of a set of eight point scatterers shown in isometric and R'_x-R'_y plane views at $R'_z = -z_o, 0, z_o$. $x_o = y_o = z_o = 100$ cm.

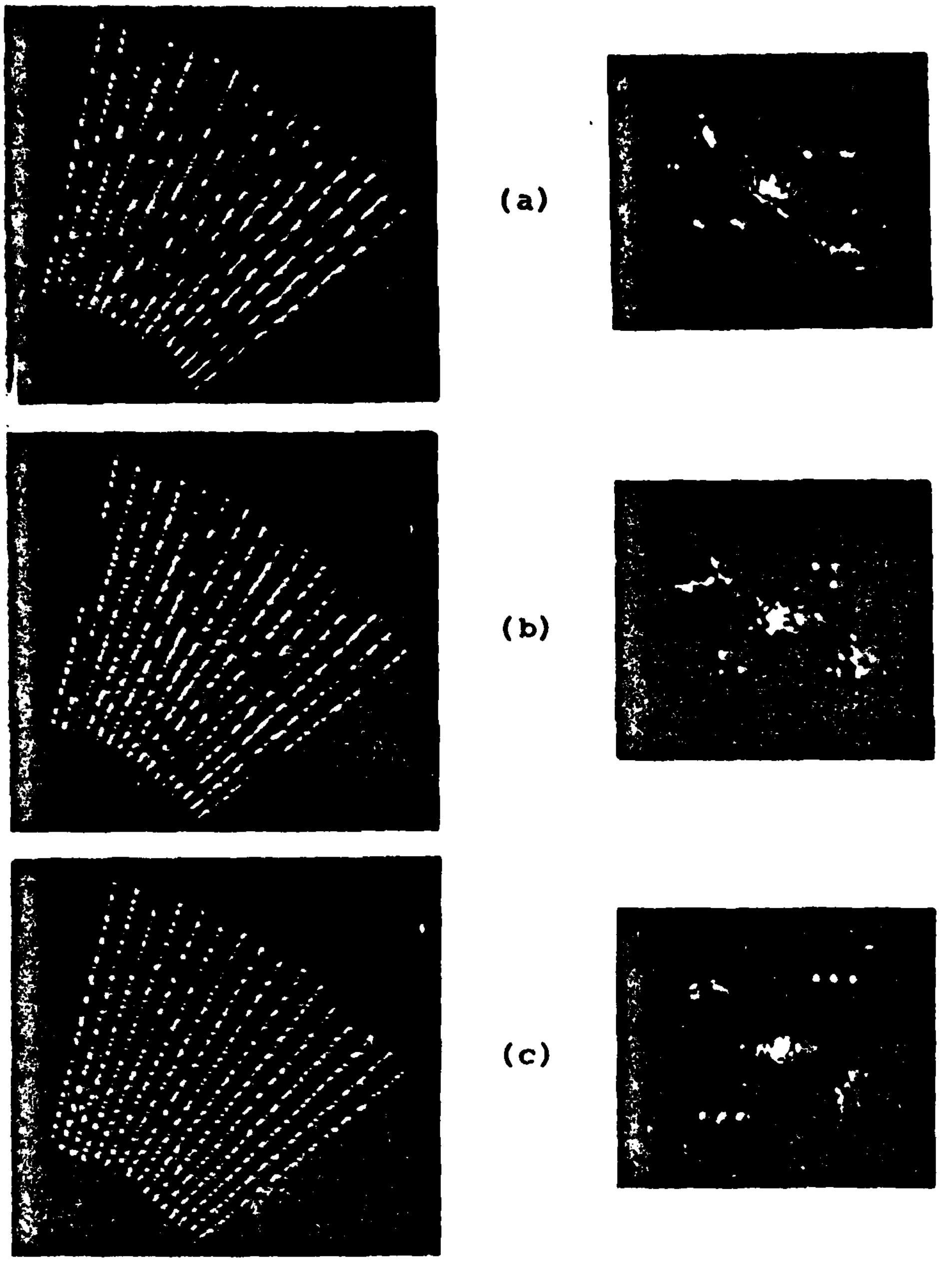


Fig. 4. Projection holograms and their optical reconstructions for the set of point scatterers in Fig.7.10 at different R_z' planes. (a) Hologram and reconstructed image of scatterers at $R_z'=-z_o$ plane. (b) Hologram and image at $R_z'=0$ plane. (c) Hologram and image at $R_z'=z_o$ plane. $x_o=y_o=z_o=100$cm.

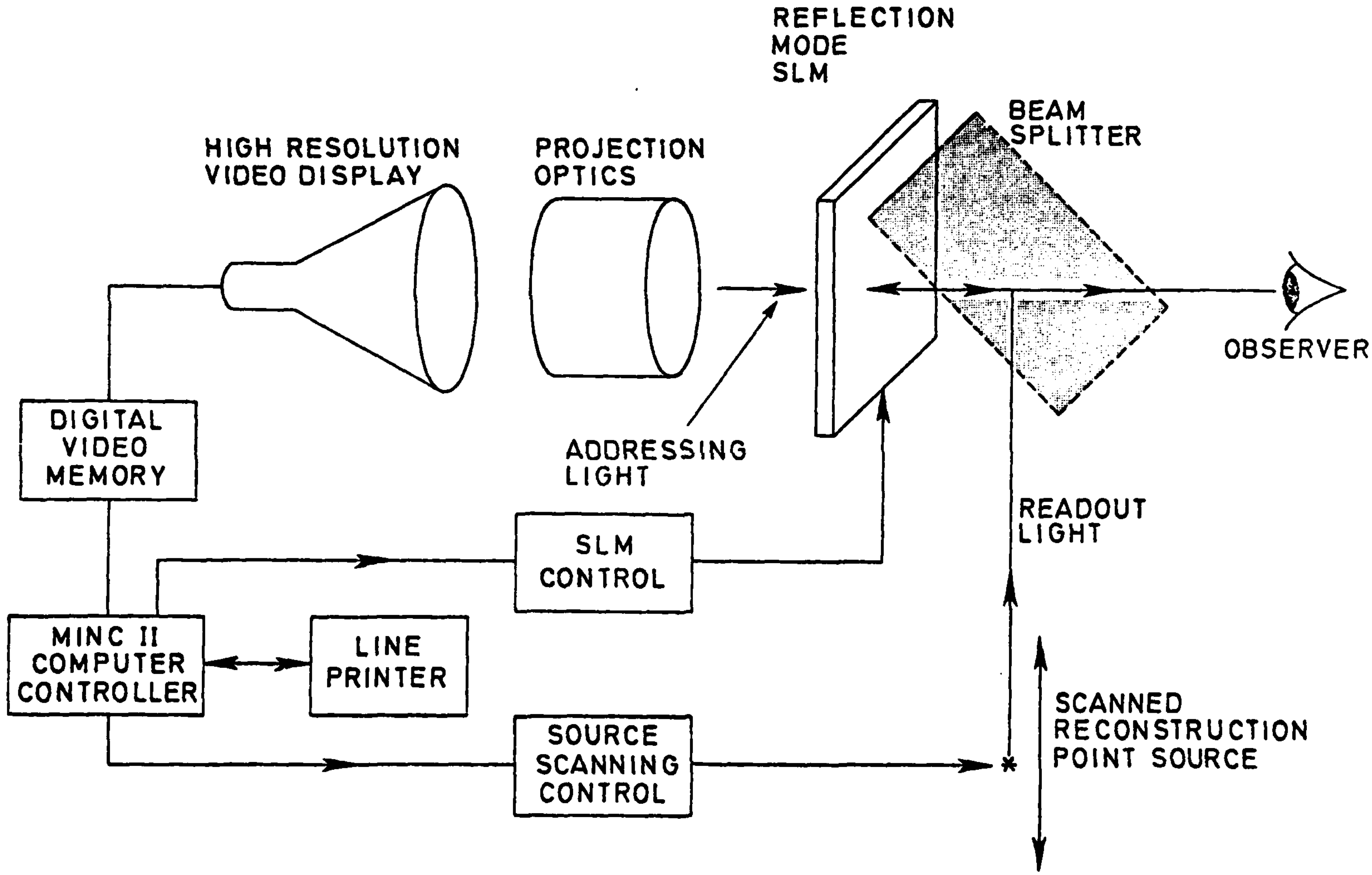


Fig. 5. True 3-D image reconstruction based on the virtual Fourier transform.

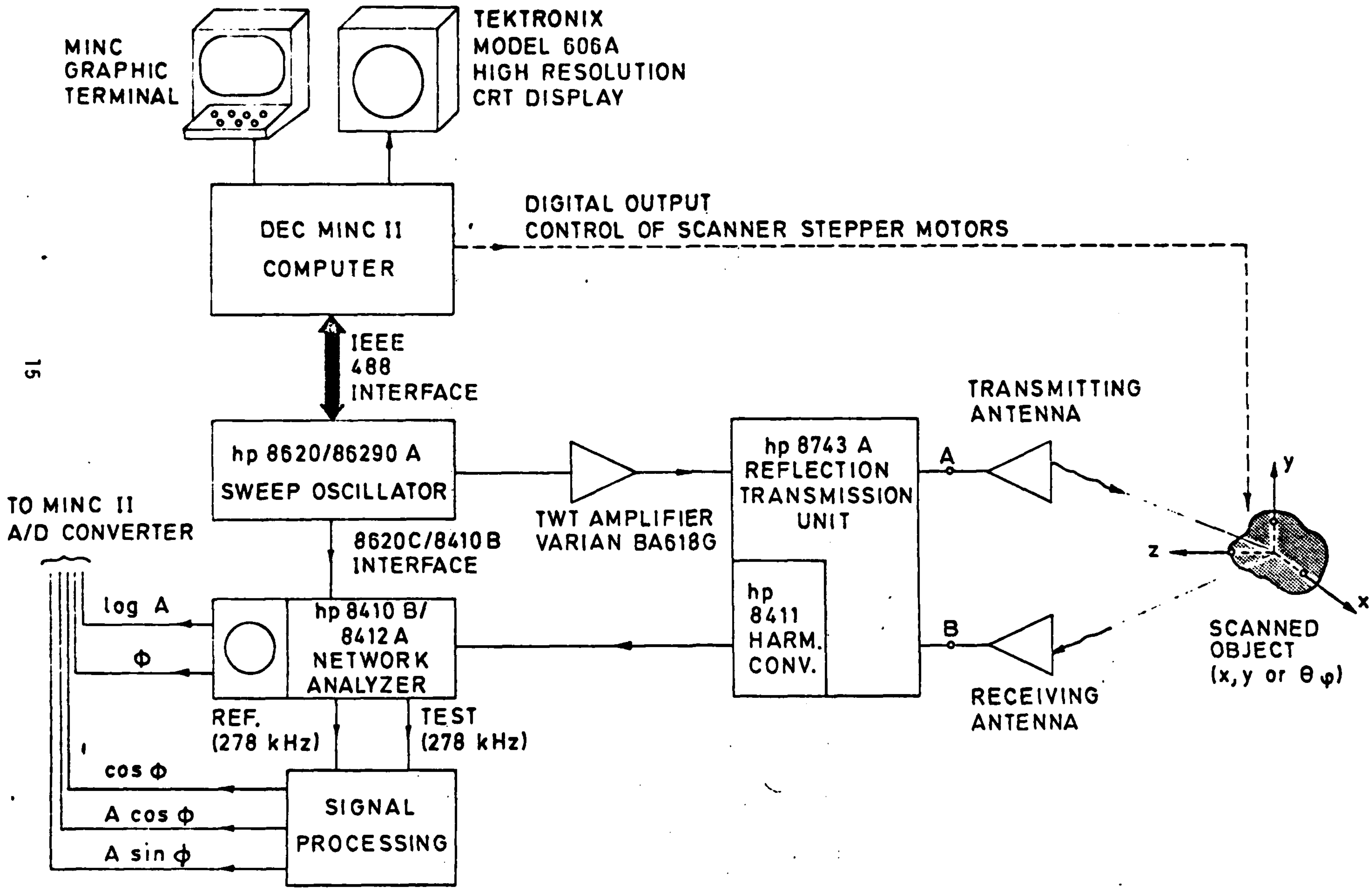


Fig. 6. Block Diagram of Automated Microwave Network Analyzer Showing Interface to MINC II Computer via IEEE 488 Standard Interface Bus.

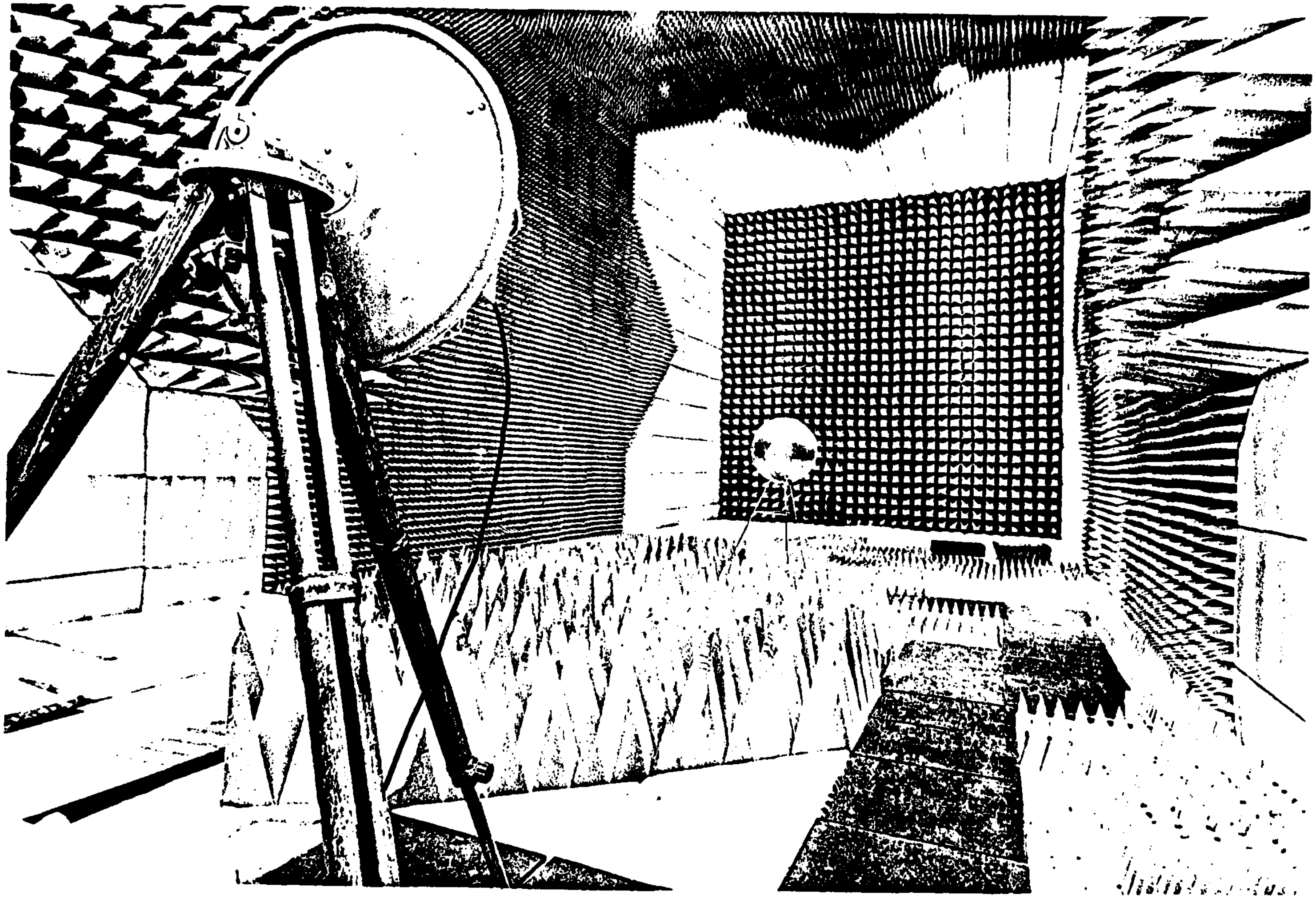
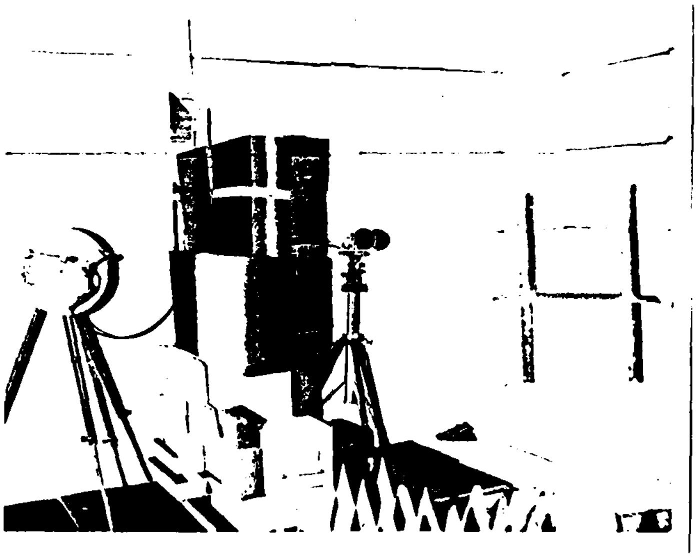
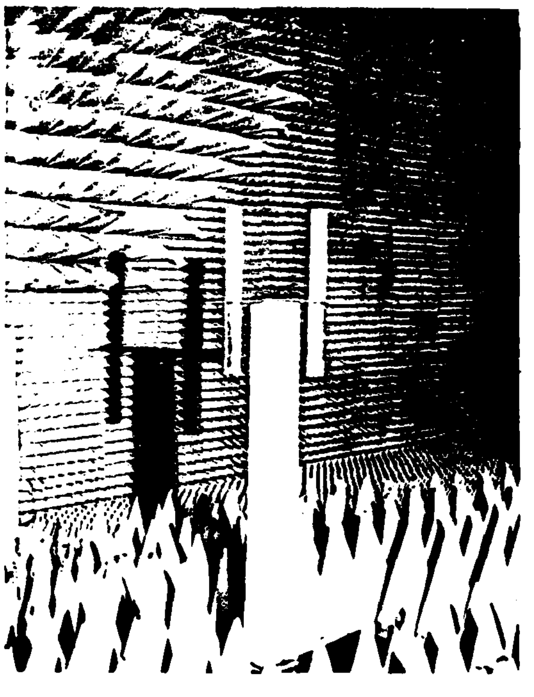


Fig. 7. View of Microwave Anechoic chamber showing illuminator antenna and a calibration sphere in background.



(a)



(b)

Fig. 8. Two views of dual-cylinder test object in Anechoic chamber. (a) View showing illuminator to the left and the receiving horn on the right separated by absorbing barrier. (b) View showing test object mounted on rotating styrofoam pedastel. Cylinders are 5 cm in diameter, 50 cm long, 25 cm apart.

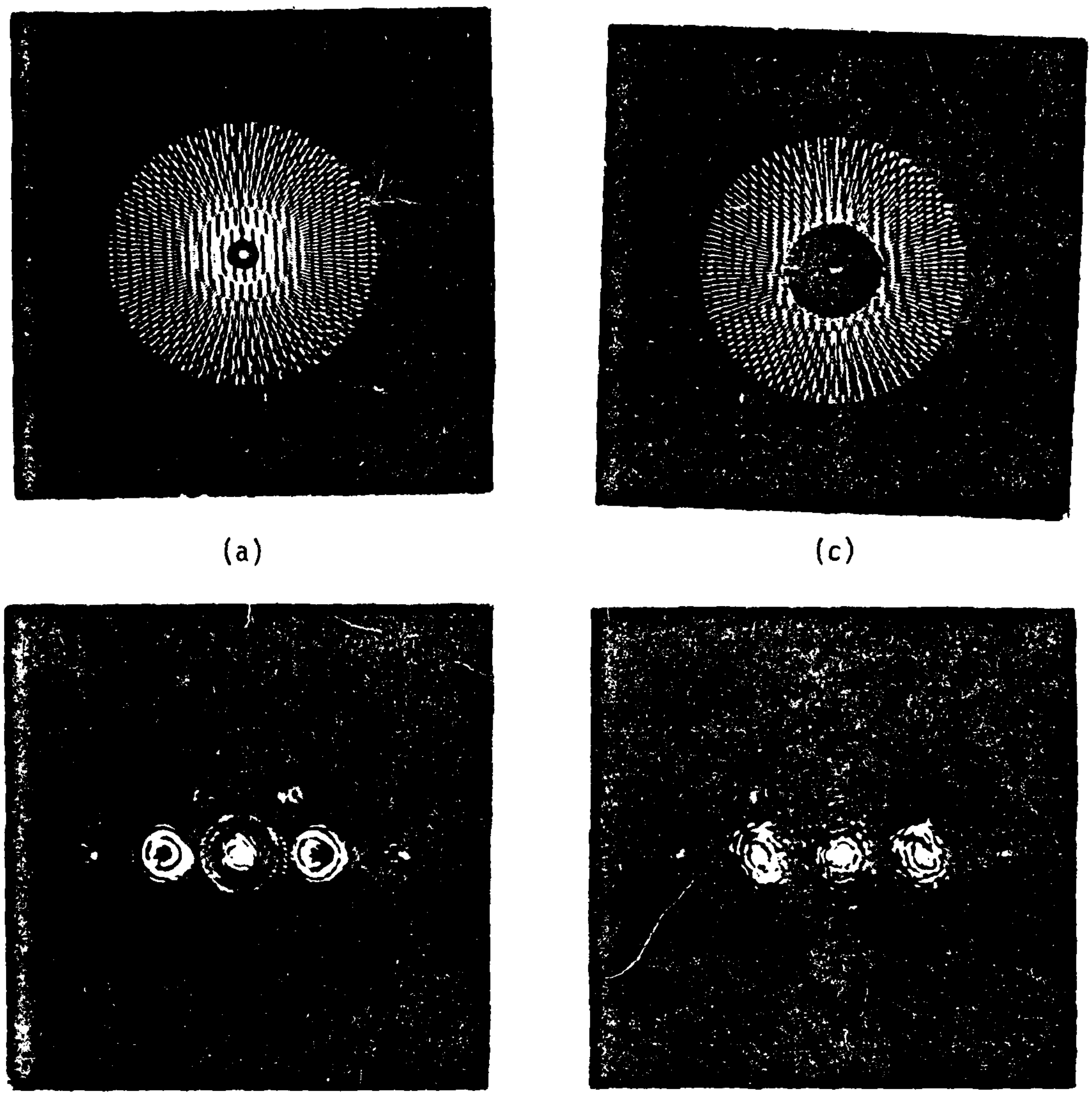


Fig. 9. Frequency swept holograms and retrieved images for a dual-cylinder test object. (a) Computed frequency swept hologram for a (2-18)GHz sweep and (b) retrieved image; (c) measured frequency swept hologram for a (5-14)GHz sweep and (d) retrieved image.

APPENDICES

APPENDIX I

The Frequency Displaced Target Derived Reference

A second TDR method which we refer to as a *Frequency Displaced Target Derived Reference* (FDTDR) method also shows promise. This method involves simultaneous illumination of the object with two phase locked imaging frequencies ω_1 and $\omega_2 = \omega_1 + \Delta\omega$ that differ by a small frequency increment $\Delta\omega$. Referring to eq. (9) of ref. 10 (see list of publications) we can write for the far field at a given receiver location R_R,

$$\psi_1(k_1,R_R) = \frac{jk_1}{2\pi R_R} e^{-jk_1(R_T+R_R)} \int U(\bar{r})\, e^{-j\,\bar{p}_1\cdot\bar{r}}\, d\bar{r} \quad (1)$$

$$\psi_2(k_2,R_R) = \frac{j(k_1+\Delta k)}{2\pi R_R} e^{-jk_1(R_T+R_R)} e^{-j\Delta k(R_T+R_R)}$$

$$x\int U(\bar{r}) e^{-j\bar{p}_1 \left(1+\frac{\Delta\omega}{\omega 1}\right)\cdot\bar{r}} d\bar{r} \quad (2)$$

where $k_{1,2} = \omega_{1,2}/c$ and $\Delta k = \Delta\omega/c$.

By making $\Delta\omega/\omega \ll 1$ the integral in (2) will approach that in (1). The only difference between the far fields ψ_1 and ψ_2 at the receivers is then the phase term $\Delta k(R_T + R_R)$. Measurement of this phase difference yields $(R_T + R_R)$ since Δk is known. This information can be used to correct the phase of either the ψ_1 or ψ_2 signals to obtain the required $\bar{p}$-space information.

$$\Gamma(\bar{p}) = \int U(\bar{r})\, e^{j\,\bar{p}\cdot\bar{r}}\, d\bar{r} \quad (3)$$

Appendix II

HOLOGRAPHY, WAVE-LENGTH DIVERSITY AND INVERSE SCATTERING

ABSTRACT

The use of wavelength diversity to enhance the performance of thinned coherent imaging aperatures is discussed. It is shown that wavelength diversity lensless Fourier transform recording arrangements that utilize a reference point source in the vicinity of the object can be used to access the three-dimensional Fourier space of non-dispersive perfectly reflecting or weakly scattering objects. Hybrid (opto-digital) computing applied to the acquired 3-D Fourier space data is shown to yield tomographic reconstruction of 3-D image detail either in parallel or meridonal (central) slices. Because of an inherent ability of converting spectral degrees of freedom into spatial 3-D image detail true super-resolution is achieved together with suppression of coherent noise. The similarity of the key equations derived to those of inverse scattering theory is pointed out and the feasibility of using other forms of broadband radiation such as impulsive, noise and thermal is discussed. Finally, the potential of utilizing wavelength diversity imaging in microscopy and telescopy are discussed.

INTRODUCTION

A frequently encountered question in the science of image formation is how to make an available aperature collect more information about the scene or object being imaged in order to enhance its resolving power beyond the classical Rayleigh limit. This process is known as super-resolution and is relevant to all imaging systems whether holographic or conventional. There are five known methods for achieving super-resolution. These include: weighting or apodization of the aperature data[1,2]; analytic continuation of the wavefield measured over the aperature[3,4]; use of evanescent wave illumination[5]; maximum entropy method[6]; and use of the time channel[7]. Weighting and analytical continuation techniques are known to become rapidly ineffective as the signal to noise ratio of the data collected decreases. Maximum entropy techniques are known to be more robust as far as noise is concerned but involve ususally extensive computation. Illumination with evanescent waves is practical in limited situations where full control of the recording arrangement exists as in microscopy for example.

This leaves the time channel approach in which one can collect in time more information about the object through the available recording aperature by altering the object aspect relative to the aperature by means of roation or linear motion[8,9] or by altering the parameters of the illumation such as directions of incidence, wavelength and/or polarization. These later operations are known to increase the degrees of freedom of the wavefields impinging on the recording aperature enhancing thereby their ability to convey information about the nature of the scattering object. Sophisticated imaging systems endevour to convert the nonspatial degrees of freedom of the wavefield, e.g., angular, spectral and polarization to spatial image detail enhancing thereby the resolution capability beyond the classical Rayleigh limit of the available physical aperature. Obviously such procedures involve more signal processing than that performed by conventional imaging with lens systems or holography.

In this paper we consider generalizing the holographic concept to include wavelength diversity as a means of enhancing resolution. A quick examination of the basic equations of holography reveals that the lensless Fourier transform hologram recording arrangement is amenable to this generalization. This conclusion is used then as a starting point for a Fourier optics formulation of wavelength diversity imaging of 3-D (three dimensional) nondispersive objects. The results show that measurement of the multiaspect or multistatic frequency (or wavelength) response of the 3-D object permits accessing its 3-D Fourier space. The resulting formulas are identical to those obtained from a multistatic generalization of inverse scattering[10,11,12] establishing thus a clear connection between holography and the inverse scattering imaging problem. The inclusion of wavelength diversity in holography is shown to have several important features: (a) the availability of the 3-D Fourier space data permits 3-D image retrieval tomographically in parallel or meridonal (central) slices or cross-sectional outlines by the application of Fourier domain projection theorems, (b) suppression of coherent noise and speckle in the retrieved image, (c) removal of several longstanding constraints on longwave (microwave and acoustical) holography such as the impractically high cost of the aperatures needed, the inability to view a true 3-D image as in optical holography because of a wavelength scaling problem, and minimization of the effects of resonances on the object.

WAVELENGTH DIVERSITY

We start by inquiring into the conditions under which the data from N holograms of the same nondispersive object recorded over the same aperture, each at a different wavelength, can be combined to yield a single image superior in quality to the image retrieved from any of the individual holograms.

One approach to answering the question posed above would be to determine the conditions under which the well known formulas[13] for the focusing condition, magnification and image location in holography can be made independent of wavelength. This quickly leads to the conclusion that wavelength independence can be met if a reference point source centered on the object is used and proper scaling of the individual holograms by the ratio of recording to the reconstruction wavelength is performed before super-position[15,24]. The former condition is that for recording a lensless Fourier transform hologram[14] where the presence of the reference point source in the object plane leads to the recording of a Fraunhofer diffraction pattern of the object rather than its Fresnel diffraction pattern because of the elimination of a quadratic phase term in the object wavefield in the recorded hologram. This is known to result in a highly desirable reduction in the resolution required from the hologram recording medium and is therefore of practical importance especially in nonoptical holography. More detail of the processing involved in combining the data in multi wavelength hologram can be found elsewhere[15].

Additional insight into the process of attaining super-resolution by wavelength diversity is obtained by considering the concept of wavelength or frequency synthesized aperature [16-20]. The synthesis of a one dimensional aperature by wavelength diversity is based on the simple fact that the Fraunhofer or far field diffraction pattern of a nondispersive planar object changes its scale, i.e. it "breathes", but does not change its shape (functional dependence), as the wavelength is changed. A stationary array of broadband sensors capable of measuring the complex field variations deployed in this breathing diffraction pattern at suitably chosen locations would sense different parts of the diffraction pattern as the wavelength is altered collecting thereby more information on the nature of the diffraction pattern and therefore on the object that gave rise to it than if the wavelength was fixed (stationary diffraction pattern). Each stationary sensor in the array is thus able to collect as the wavelength is changed, and the breathing diffraction pattern sweeps over it, the same set of data or information collected by a movable sensor mechanically scanned over the appropriate part of the diffraction pattern when it is kept stationary by fixing the wavelength. Hence the term wavelength or frequency synthesized aperture.

The orientation and location of the wavelength synthesized aperture for any planar distribution of sensors deployed in the Fraunhofer diffraction pattern of a planar object and the retrieval of an image from the data collected has been treated earlier[16,17]. It was clear, however, that extension of the wavelength diversity concept to the case of 3-D objects is necessary before its generality and practical use could be established.

For this purpose we considered[20] as shown in Fig. 1(a) an isolated planar object of finite extent with reflectivity $D(\bar{\rho}_o)$, where $\bar{\rho}_o$ is a two dimensional position vector in the object plane (x_o, y_o). The object is illuminated by a coherent plane wave of unit-amplitude and of wave vector $\bar{k}_i = k\, \bar{1}_{k_i}$ produced for example by a distant source located at $\bar{R}_T$. The wavefield scattered by the object is monitored at a receiving point designated by position vector $\bar{R}_R$ belonging to a recording aperture lying in the far field region of the object. The receiving point will henceforth be referred to as the receiver and the source point at the transmitter. The position vectors $\bar{\rho}_o$, $\bar{R}_T$ and $\bar{R}_R$ are measured from the origin of a cartesean coordinate system (x_o, y_o, z_o) centered in the object. The object is assumed to be nondispersive i.e., D is independent of k. However, when the object is dispersive such that $D(\bar{\rho}_o,k) = D_1(\bar{\rho}_1)D_2(k)$ and $D_2(k)$ is known, the analysis presented here can easily be modified to account for such object dispersion by correcting the data collected for $D_2(k)$ as k is changed.

Referring to Figure 1(a) and ignoring polarization effects, the field amplitude at $\bar{R}_R$ caused by the object scattered wavefield may be expressed as,

$$\psi(k,\bar{R}_R) = \frac{jk}{2\pi} \int D(\bar{\rho}_o) e^{-j\bar{k}_i \cdot \bar{r}_T} \frac{e^{-jk\, r_R}}{r_R}\, d\bar{\rho}_o \tag{1}$$

where $d\bar{\rho}_o$ is an abbreviation for $dx_o dy_o$ and the integration is carried out over the extent of the object. Noting that $\bar{r}_T = \bar{\rho}_o - \bar{R}_T$, $\bar{R}_T = -R_T \bar{1}_{k_i}$ and using the usual approximations valid here: $r_R \simeq R_R + \rho_o^2/2R_R - \bar{1}_R \cdot \bar{\rho}_o$ for the exponential in (1) and $r_R \simeq R_R$ for the denominator in (1) where $\bar{1}_R = \bar{R}_R/R_R$ and $\bar{1}_{k_i} = \bar{k}_i/k$ are unit vectors in the $\bar{R}_R$ and $\bar{k}_i$ directions respectively, one can write eq. (1) as,

$$\psi(k, \bar{R}_R) = \frac{jk}{2\pi R_R}\, e^{-jk(R_T + R_R)} \int D(\bar{\rho}_o)\, e^{-j\,\bar{p}\,\cdot\,\bar{\rho}_o}\, d\bar{\rho}_o, \tag{2}$$

where we have used the fact that the observation point is in the far field of the object so that $\exp\,(-jk\,\rho_o^2/2R_R)$ under the integral sign can be replaced by unity. In eq. (2), $\bar{p} = k\,(\bar{1}_{k_i} - \bar{1}_R) \triangleq p_x\,\bar{1}_x + p_y\,\bar{1}_y + p_z\,\bar{1}_z$ is a three dimensional vector whose length and orientation depend

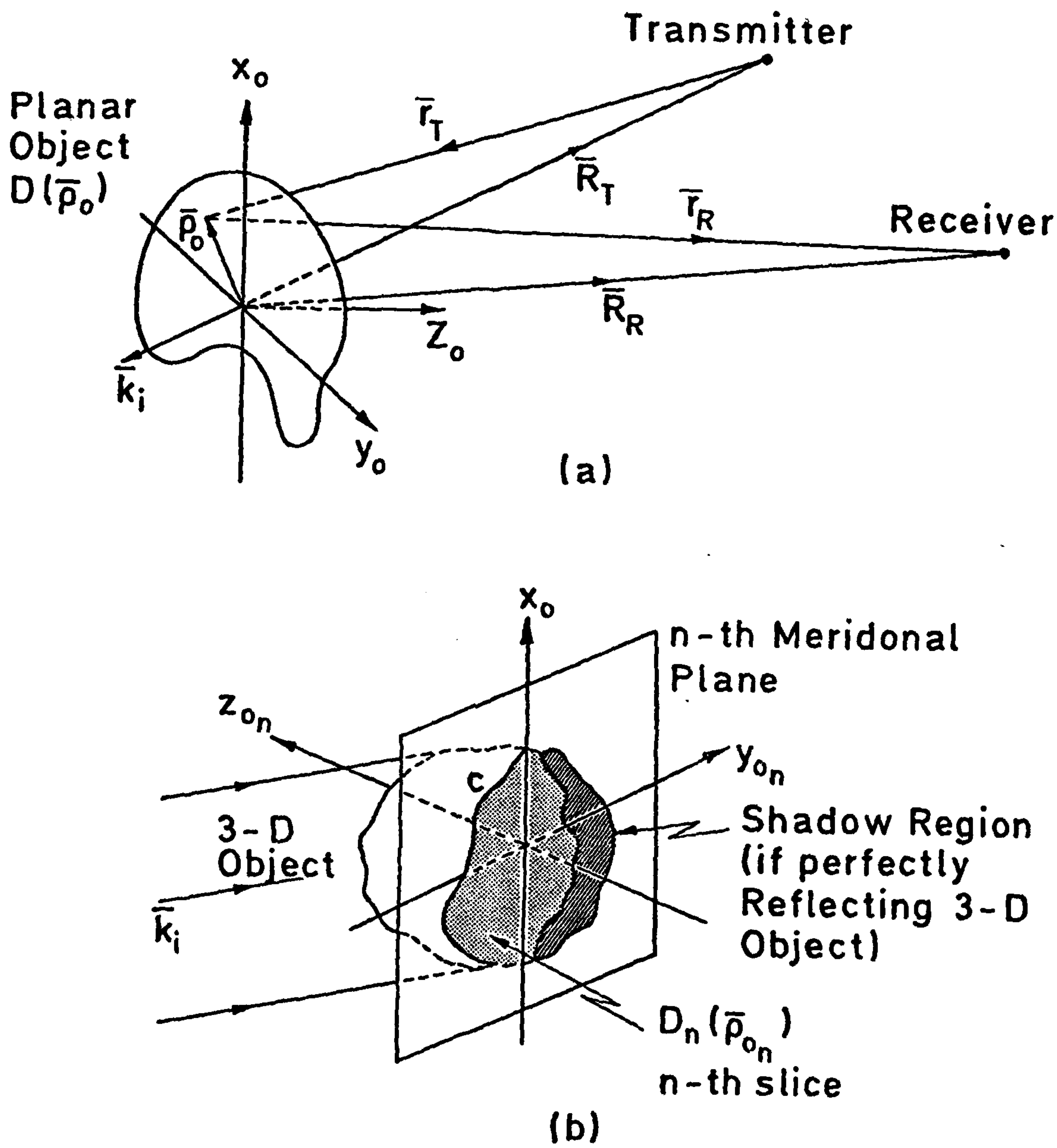


Fig. 1. Geometries for wavelength diversity imaging. (a) Two dimensional object, (b) Three dimensional object with the n-th meridonal (central) slice and cross sectional outline c shown.

on the wavenumber k and the angular positions of the transmitter and the receiver. For each receiver and/or transmitter present, $\bar{p}$ indicates the position vector for data storage. An array of receivers for example would yield therefore as k is changed (frequency diversity) or as $\bar{k}$ $(=k\bar{I}_{k_i})$ is charged (wave-vector diversity) a 3-D data manifold. The projection of this 3-D data manifold on the object plane yields $\psi(k,R_T)$ because $\bar{p} \cdot \bar{\rho}_o = \bar{p}_t \cdot \bar{\rho}_o = p_x x_o + p_y y_o$ where $p_x = k(\bar{I}_{k_i} - \bar{I}_R)_x$ and $p_y = k(\bar{I}_{k_i} - \bar{I}_R)_y$ are the cartesian components of the projection $\bar{p}_t$ of $\bar{p}$ on the object plane. Accordingly eq. (2) can be expressed as,

$$\psi(k, R_R) = \frac{jk}{2\pi R_R} e^{-jk(R_T + R_R)} \int D(x_o,y_o)\, e^{-j(p_x x_o + p_y y_o)}\, dx_o dy_o \tag{3}$$

Because of the finite extent of the object, the limits on the integral can be extended to infinity without altering the result. The integral in (3) is recognized then as the two dimensional Fourier transform $\tilde{D}(p_x,p_y)$ of $D(x_o,y_o)$. It is seen to be dependent on the object reflectivity function, the angular positions of the transmitter and the receiver and on the values assumed by the wavenumber k but is entirely independent of range. Information about D can thus be collected by varying these parameters. Note that the range information is contained solely in the factor $F = jk \exp[-jk(R_T + R_R)]/2\pi R_R$ preceeding the integral. The field observed at $\bar{R}_R$ has thus been separated into two terms one of which, the integral $\tilde{D}$, contains the lateral object information and the other F, contains the range information. The presence of F in eq. (3) hinders the imaging process since it complicates data acquisition and if not removed, gives rise to image distortion because R_R is generally not the same for all receivers. To retrieve an image of the object via a 2-D Fourier transform of eq. (3), the factor F must first be eliminated. Holographic recording of the complex field amplitude given in (3) using a reference point source located at the center of the object will result in the elimination of the factor F and the recording of a Fourier transform hologram. This operation yields $\tilde{D}$ over a two dimensional region in the p_x,p_y plane. The size of this region, which determines the resolution of the retrieved image depends on the angular positions of the transmitter and the receiver and on the values assumed by k, i.e. the extent of the spectral window used. The later dependence on k implies super-resolution imaging capability because of the frequency synthesized dimension of the 2-D data manifold generated. Because of the dependence of resolution on the relative positions of the object, the transmitter, and receiving aperture, the impulse response is clearly spatially variant. In fact a receiver point situated at $\bar{R}_R$ for which $\bar{p}$ is normal to the object

plane can not collect any lateral object information because for this condition ($\bar{p} \cdot \bar{\rho}_o = 0$) the integrals in (2) and (3) yield a constant. Such receiving point is located in the direction of specular reflection from the object where the diffraction pattern is stationary i.e. does not change with k. In this case the observed field is solely proportional to F containing thus range information only. Obviously this case can easily be avoided through the use of more than one receiver which is required anyway when 2-D or 3-D object resolution is sought[20,21].

The analysis presented above can be extended to three dimensional objects by viewing a 3-D object as a collection of thin merdional or central slices as depicted in Fig. 1(b) each of which representing a two dimensional object of the type analyzed above. With the n-th slice we associate a cartesean coordinate system x_o, y_{o_n}, z_{o_n} that differ from other slices by rotation about the common x_o axis. Since the vectors $\bar{p}$, $\bar{R}_T$ and $\bar{R}_R$ are the same in all n-coordinate systems, eq. (3) holds. $\psi_n(k,\bar{R}_R)$ is then obtained from projection of the three dimensional data manifold collected for the 3-D object on the x_o, y_{on} plane associated with the n-th slice. An image for each slice can then be obtained as described before. An inherent assumption in this argument is that all slices are illuminated by the same plane wave. This is a reasonable approximation when the 3-D object is weakly scattering and the Born approximation is applicable or when the 3-D object is perfectly reflecting and does not give rise to multiple reflections between its parts. In the later case the two dimensional meridonal slices $D_n(\bar{\rho}_{o_n})$ deteriorate into contours, such as C in Fig. 1(b) defined by the intersection of the meridonal planes with the illuminated portion of the surface of the object. Accordingly we can write for the n-th meridonal slice or contour,

$$\psi_n(k,R_R) = F \int D_n(\bar{\rho}_{o_n})\, e^{-j\bar{p}.\bar{\rho}_{o_n}}\, d\bar{\rho}_{o_n} \tag{4}$$

We can regard $D_n(\bar{\rho}_{o_n})$ as the n-th meridonal slice or contour of a three dimensional object of reflectivity $U(\bar{r})$ where $\bar{r}$ is a three dimensional position vector in object space. This means that $D_n(\bar{\rho}_{o_n}) = U(\bar{r})\ \delta(z_{o_n})$ where δ is the Dirac delta "function". Consequently eq. (4) becomes,

$$\psi_n(k,R_R) = F \int U(\bar{r})\, \delta\, (z_{o_n})\; e^{-j\bar{p}.\bar{\rho}_{o_n}}\, d\bar{\rho}_{o_n}$$

$$= F \int U(\bar{r})\, \delta\, (z_{o_n})\; e^{-j\bar{p}.\bar{r}}\, d\bar{r} \qquad (5)$$

where $d\bar{r}$ designated an element of volume in object space and where the last equation is obtained by virture of the sifting property of the delta function.

Summing up the data from all slices or contours of the object we obtain,

$$\sum_n \psi_n = F \int U(\bar{r})\; e^{-j\bar{p}.\bar{r}}\, d\bar{r} = \psi(\bar{p}) \qquad (6)$$

because

$$\sum_n U(\bar{r})\, \delta\, (z_{o_n}) = U(\bar{r}).$$

Assuming that the Factor F in eq. (6) is eliminated as before, equation (6) reduces to

$$\psi(\bar{p}) = \int U(\bar{r})\, e^{-j\bar{p}.\bar{r}}\, d\bar{r} \qquad (7)$$

which is the 3-D Fourier transform of the object reflectivity $U(\bar{r})$. Wavelength diversity permits therefore accessing the 3-D Fourier space of a nondispersive object providing thereby the basis for 3-D Lensless Fourier transform holography. An alternate formulation to that given above of super-resolved wave-vector diversity imaging of 3-D perfectly conducting objects is possible[22] by extending the formulation of the inverse scattering imaging problem[10,11] to the multistatic case, along lines that are similar but somewhat different than those given by Raz[12]. The resulting scalarized formulas are identical to (7) establishing thus the connection between the holographic and the inverse scattering approaches to the imaging problem.

THREE DIMENSIONAL IMAGE RETRIEVAL

The above considerations of multiwavelength holography have lead us to determining a means by which the 3-D Fourier space of the object can be accessed employing synchroneous detection. It is clear that once the 3-D Fourier space data is available, 3-D image detail can be retrieved by means of an inverse 3-D Fourier transform which can be carried out digitally. Alternately, holographic techniques

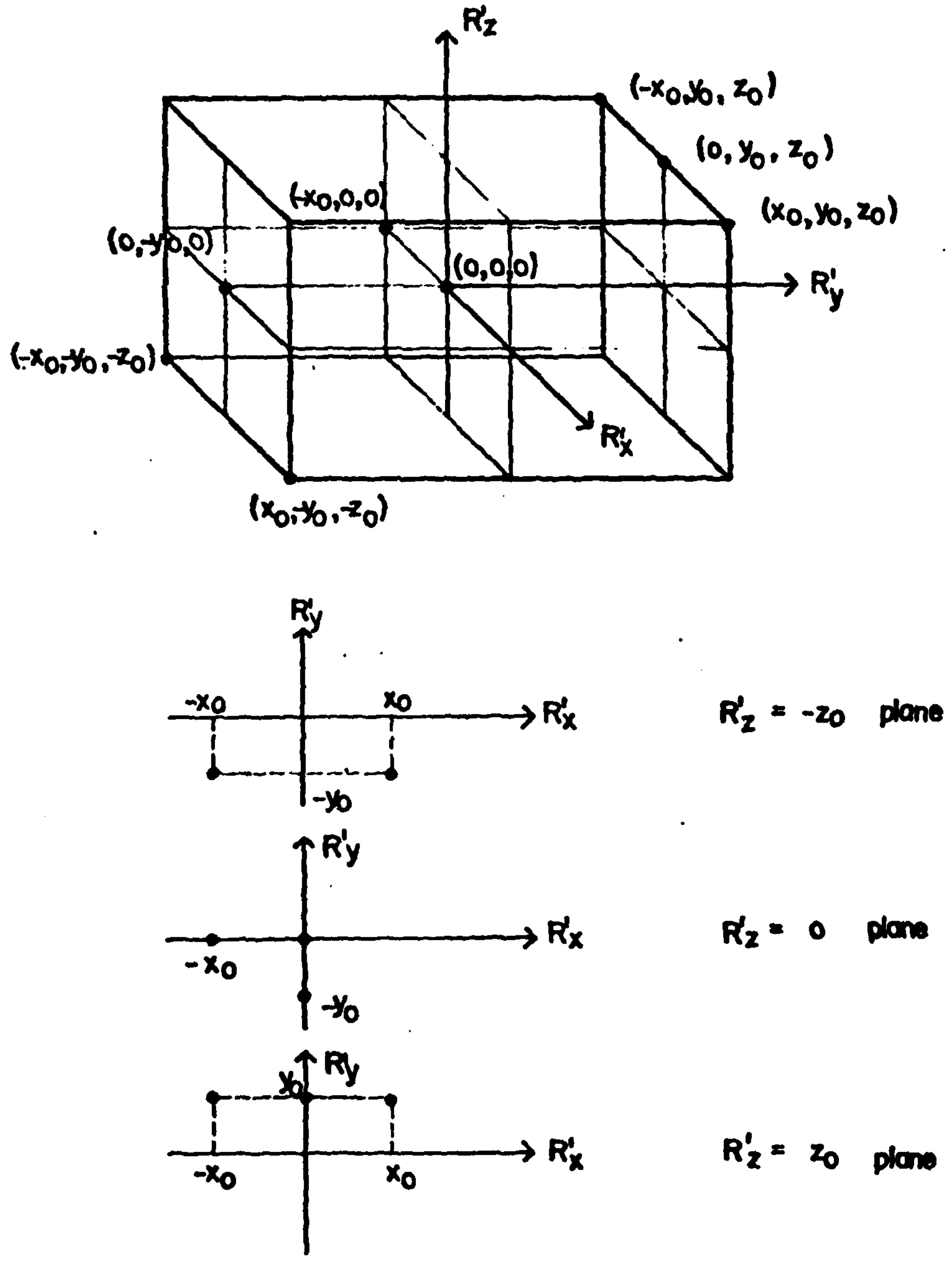


Fig. 2. 3-D object consisting of a set of eight point scatterers shown in isometric and R_x'-R_y' plane views at R_z'=$-z_o$,0,z_o. x_o=y_o=z_o =100 cm.

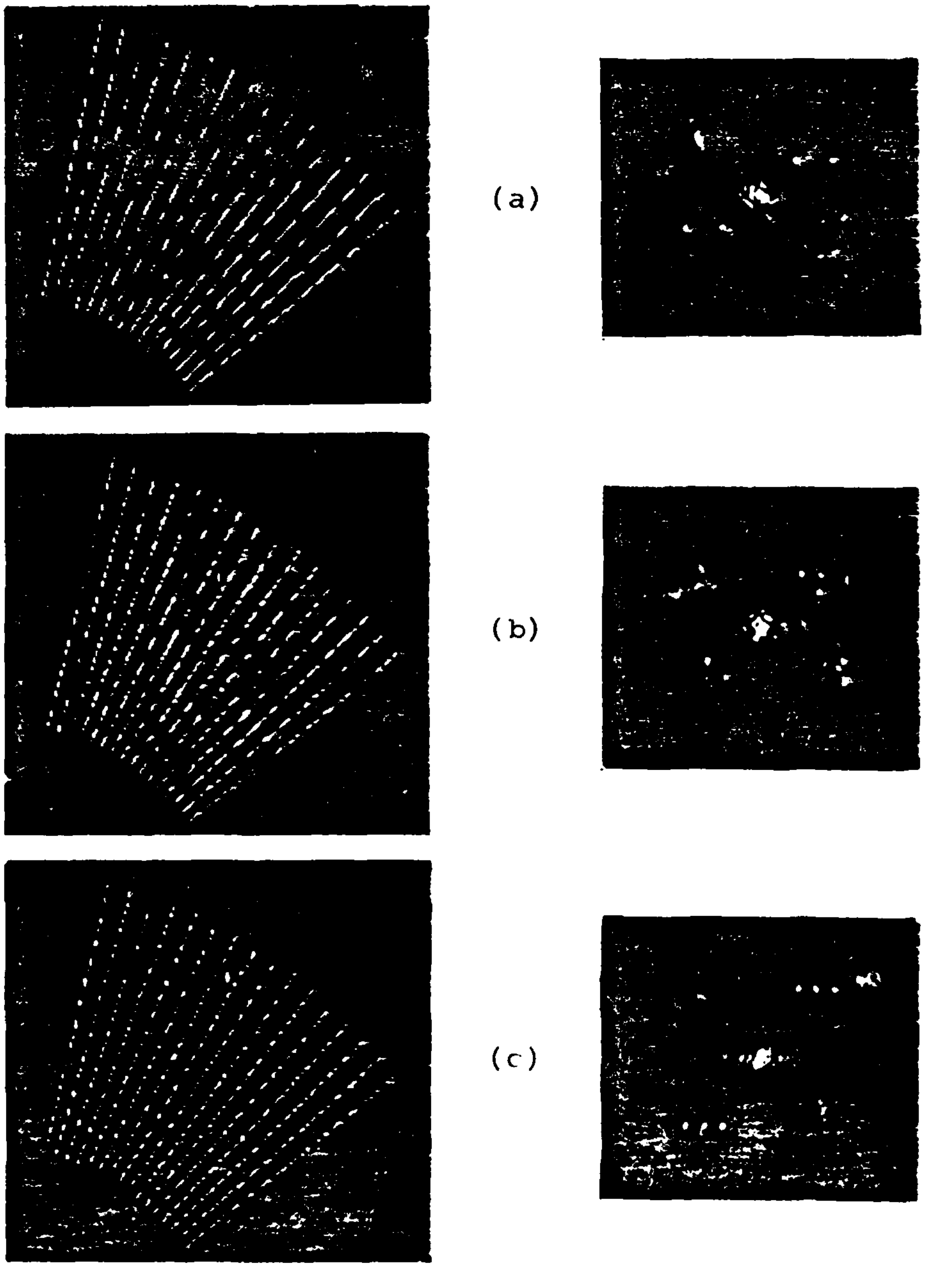


Fig. 3. Projection holograms and their optical reconstructions for the set of point scatterers in Fig. 2 at different R_z' planes. (a) Hologram and reconstructed image of scatterers at $R_z'=-z_0$ plane. (b) Hologram and image at $R_z'=0$ plane. (c) Hologram and image at $R_z'=z_0$ plane. $x_0=y_0=z_0=100$ cm.

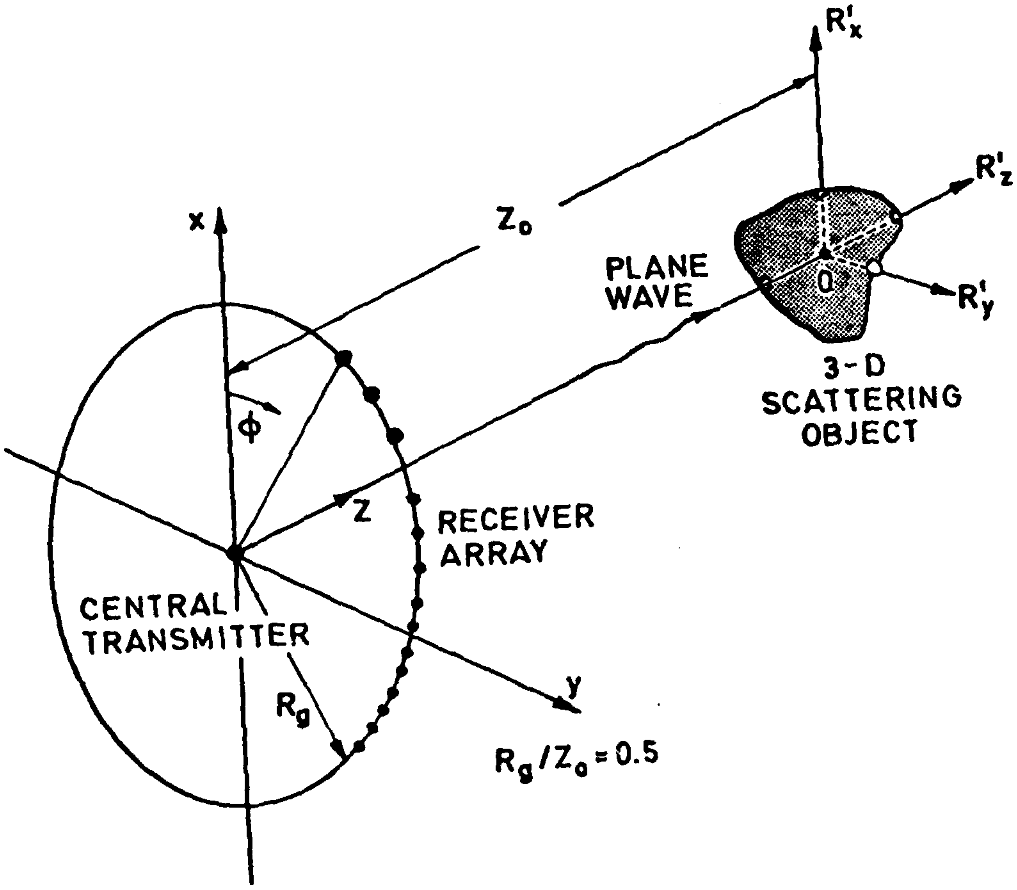


Fig. 4. Arrangement used in computer simulation of wavelength diversity imaging.

can be invoked again. Fourier domain projection theorems[23] that are dual to the spatial domain projection theorem[25,26] can be applied to the Fourier space data to produce a series of projection holograms from which 2-D images of meridonal or parallel slices of the object can be retrieved on the optical bench[20]. This procedure does not involve any specific scaling of the size of the optical hologram transparency relative to the size of the original recording aperture by the ratio of the recording to the reconstruction wavelengths as in longwave holography where the scaling necessary for viewing a 3-D image free of longitudinal distortion ususally leads to an impractically minute equivalent hologram transparancy that cannot be readily viewed by an observer. The lateral and longitudinal resolutions in the retrieved image depend now on the dimensions of the volume in Fourier space accessed by wavelength diversity. This volume depends on the wavelength range and on the recording geometry. Thus the longitudinal resolution does not deteriorate now as rapidly with range as in conventional monochromatic imaging systems.

An example of computer simulations of frequency diversity holographic imaging of a 3-D object consisting of eight point scatterers distributed as shown in Fig. 2 is given in Fig. 3. Shown in Fig. 3 are three weighted Fourier domain projection holograms and the corresponding optically retrieved images for three equally spaced parallel slices of the object containing distinguishable 2-D distributions of scatterers. The simulated recording arrangement shown in Fig. 4 consisted of an array of 16 receivers equally distributed on an arc extending from $\phi = 40^{\circ}$ to $\phi = 77.5^{\circ}$ surrounding a central transmitter capable of providing plane wave illumination of the object. The results shown were obtained with microwave imaging in mind assuming a frequency sweep of (2-4)GHz. They clearly indicate a leteral and longitudinal resolution capability of the order of 25 cm. Wider sweep widths yield better resolution. For example a (1-18)GHz sweep would yield a 3-D resolution of the order of 1.5 cm.

DISCUSSION AND CONCLUSIONS

Seeking means by which the information content in a hologram can be increased for example by wavelength diversity we have arrived at a formulation of 3-D Lensless Fourier transform holography capable of furnishing 3-D image detail tomographically. This ability of producing 3-D images in slices from coherently detected wavefields enable us to regard the method also as coherent tomography. The Fourier space accessed in the above fashion by wavelength diversity can be viewed as a generalized 3-D hologram in which one dimension has been synthesized by wavelength diversity. Such a generalized hologram contains not only spatial amplitude and phase data as in conventional holography but also spectral information and hence can yield better

resolution than the classical Rayleigh limit of the available aperture operating at the shortest wavelength of the spectral window used. This super-resolving property is further enhanced through an inherent suppression of the effects of object resonances and coherent noise in the retrieved image, the latter being so because frequency diversity tends to make the impulse response of the system unipolar resembling that of a non-coherent imaging system that is free of speckle and coherent noise artifacts[15]. Futher enhancement of information content and resolution can be achieved by polarization diversity where the $\bar{p}$ space can be multiply accessed for different nonredundant polarizations of the illumination and the receivers and the resulting polarization diversity images added either coherently or non-coherently in order to achieve a degree of noise averaging as discussed elsewhere[15].

The removal of several longstanding constraints on conventional longwave (microwave and acoustic) holography attained through the use of wavelength diversity as described here leads to a new class of imaging systems capable of converting spectral degrees of freedom into 3-D spatial image detail furnishing thereby true super-resolution. Wavelength diversity is applicable to the imaging of two classes of objects: perfectly reflecting objects of the type encountered in radar and sonar and weakly scattering objects of low or known dispersion of the type encountered in biology and medicine. The practical application of the concepts presented here to optical wavefield is presently under consideration. The availability of tunable dye lasers and electronic imaging devices suggest interesting possibilities of three dimensional wavelength diversity microscopy. Here one can conceive of an arrangement in which a minute semitransparent object with homogeneous or known dispersion is transilluminated by a collimated coherent light beam from a tunable dye laser which can also be made to provide a coherent reference point source in the immediate vicinity of the object. The resulting reference and the object scattered wavefields are intercepted by the photocathode of an electronic imaging device of known spectral response such as a vidicon. Because of the minute size of the object, the photocathode can easily be situated in the far field of the object. Thus nearly a lensless Fourier transform hologram recording arrangement results. The spatial frequency content in the resulting hologram is therefore expected to be sufficiently low to be resolved by a high resolution electronic imaging device. By recording and digitally storing the resulting detected hologram fringe pattern as a function of dye laser wavelength one can gain access to the 3-D Fourier space of the object since $\bar{1}_{k_i}$ and $\bar{1}_R$ for the recording geometry are precisely known.

A similar recording arrangement can be envisioned in the active coherent imaging of a distant reflecting object (active telescopy) where the object can be made to furnish a reference point source situated on its surface like a wavelength independent stationary glint point or an intentionally placed retroreflector. Because in such an arrangement the reference and the object wavefields travel over the same path, atmospheric effects are expected to be minimized. The generation of an

object derived reference geometry in longwave (microwave and acoustic) wavelength diversity imaging has been described elsewhere[20,27].

Finally it is worthwhile to note that since the scattering process is linear the multiaspect or multistatic frequency or wavelength response measurements referred to in this paper can be obtained also by measuring the multiaspect impulse response followed by Fourier transformation of the individual impulse responses measured[19]. This means that impulsive illumination can also be utilized. Because the impulse response of a linear system can be measured by using random noise excitation and cross-correlating the output with the input[19], a possibility of using random noise (white light) illumination and cross-correlation detection techniques as a means for accessing the 3-D Fourier space of the object also emerges.

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APPENDIX III

THE VIRTUAL FOURIER TRANSFORM
AND ITS APPLICATION IN THREE DIMENSIONAL DISPLAY

ABSTRACT

In contrast to the well known and widely used instantaneous Fourier transforming property of the convergent lens in coherent (laser) light, the "Virtual Fourier Transform" (VFT) capability of the divergent lens is less widely known or used despite many advantages. We will review the principle of the VFT and discuss its advantages in certain applications. In particular a method for viewing the virtual Fourier transform of a two dimensional function with the naked eye using an ordinary point source will be presented. A scheme for three-dimensional image display based on a "Fourier domain projection theorem" utilizing varifocal VFT is described and a discussion of the properties of the displayed image given.

INTRODUCTION

Several sophisticated three dimensional (3-D) imaging techniques such as x-ray tomography[1], electron microscopy[2], crystallography[2], wave-vector diversity imaging and inverse scattering[3], involve measurements that give access to a finite volume in the 3-D Fourier space of a 3-D object function. A 3-D image of the original object can then be reconstructed by computing the inverse 3-D Fourier transform. The retrieved iamge normally represents the spatial distribution of a relevant parameter of the object such as absorption, reflectivity, scattering potential, etc.

Obviously, the required inverse transform can be performed digitally. Digital techniques however often preclude real-time operation particularly when the object being imaged is not simple but contains considerable resolvable intricate detail. More importantly, because of the inherent two dimensionality of CRT computer displays, direct true 3-D image display is not possible. Present day computer graphic displays are capable of displaying 3-D image detail either in seperate cross-sections or slices, or in a computed perspective (isometric) view of the object, or in some instances stereoscopically where an illusion of a 3-D scene is created in the mind of the observer who is required usually to use special viewing glasses[4,5].

Hybrid (opto-digital) computing techniques offer an alternate approach to 3-D image retrieval from 3-D Fourier space data. They furnish as shown in this paper the ability to display true 3-D image detail. The approach is based on "Fourier Domain Projection Theorems"[2,3] that are dual to "Spatial or Object Domain Projection Theorems" used in radio-astronomy[6,7] and tomography[1]. These theorems permit the reconstruction of 3-D image detail tomographically* i.e. in slices from 2-D projections of the 3-D Fourier space data[2,3]. Although the required 2-D Fourier transform can be carried out digitally, the emphasis in this paper is on coherent optical techniques for performing the 2-D Fourier transform.with particular attention to implementations that permit the execution of the necessary 2-D optical transforms of the various projection hologram sequentially in real-time. Specific attention is given to a technique that utilizes the virtual Fourier transform which permits the viewing of a virtual 3-D image in real-time.

FOURIER DOMAIN PROJECTION THEOREMS

There are two Fourier domain projection theorems. One leads to tomographic object reconstruction in parallel slcies and is called the "weighted Fourier domain projection theorem", the other leads to tomographic object reconstruction in meridonal or central slices and can therefore be called the "meridonal or central slice Fourier domain projection theorem".

We begin by considering a 3-D object function $f(\bar{r})$ with $\bar{r} = x\bar{1}_x + y\bar{1}_y + z1_z$ being a position vector in object space. Let $F(\bar{w})$ be the 3-D Fourier transform of $f(\bar{r})$ defined by,

$$F(\bar{w}) = \int f(\bar{r})\, e^{-j\bar{w}.\bar{r}}\, d\bar{r} \tag{1}$$

where $d\bar{r} = dx\,dy\,dz$ and $\bar{w} = w_x\bar{I}_x + w_y\bar{I}_y + w_z\bar{I}_z$ is a position vector in the Fourier or spatial frequency domain.

Consider next the projection of $F(\bar{w})$ on the w_x, w_y plane defined by,

$$F_p(w_x,w_y) = \int_{w_z} F(\bar{w})\, dw_z \;. \tag{2}$$

and combining eq. (1) and (2),

$$F_p(w_x,w_y) = \int_{w_z} \{\iiint_{xyz} f(x,y,z) e^{-j(w_x x + w_y y + w_z z)} dxdydz\} dw_z \tag{3}$$

---

*From the Greek work Tomos meaning slice.

Integrating with respect to w_z first and assuming that the volume in $\bar{w}$ space occupied by $F(\bar{w})$ is sufficiently large we obtain,

$$F_p(w_x,w_y) = \int_x\int_y\int_z f(x,y,z)\,\delta(z) e^{-j(w_x x + w_y y)}\,dxdydz \tag{4}$$

$$= \int_x\int_y f(x,y,o)\, e^{-j(w_x x + w_y y)}\,dxdy \tag{5}$$

The 2-D Fourier domain projection $F_p(w_x,w_y)$ and the central slice $f(x,y,o)$ through the object form thus a Fourier transform pair. This may be symbolically expressed as,

$$F_p(w_x,w_y) \leftrightarrow f(x,y,o) \tag{6}$$

Other parallel slices through the object at $z = z_n$, z_n being a constant describing the z coordinate of the n-th parallel slice, can in a similar manner be related to "weighted" Fourier domain projections of $F(\bar{w})$ defined by,

$$F_{p,n}(w_x,w_y) = \int_{w_z} F(w) e^{jz_n w_z}\,dw_z \tag{7}$$

Making use of eq. (1) and again performing the integration with respect to w_z first we obtain,

$$F_{p,n}(w_x,w_y) \leftrightarrow f(x,y,z_n) \tag{8}$$

which indicates that the weighted projection $F_{p,n}(w_x,w_y)$ and the n-th parallel object slice $f(x,y,z_n)$ form a Fourier transform pair. Equation (6) is seen to be a special case of eq. (8) when $z_n = o$.

Given the 3-D Fourier space data manifold $F(\bar{w})$ one can digitally compute and display a set of "weighted projection holograms" $F_{p,n}(w_x,w_y)$. A corresponding set of images of parallel slices or cross-sectional outlines of the 3-D object can then be retrieved via 2-D Fourier transform operations which can most conveniently be carried out optically from photographic transparency records of the weighted projection holograms displayed by the computer.

Returning to eqs. (1) and (2) one can also show that projections of $F(\bar{w})$ on arbitrarily oriented planes other than the w_x, w_y plane chosen for eq. (2), yields "meridonal projection holograms" that are 2-D Fourier transforms of corresponding merdional (central) slices of the object. This is the "meridonal Fourier domain projection theorem. It furnishes the basis for angular multiplexing of the resulting meridonal projection holograms into a single composite hologram which can be used to form a 3-D iamge of the object in a manner similar to that in integral holography[8] which is increasingly being referred to as Cross holography*.

THE VIRTUAL FOURIER TRANSFORM

In contrast to the well known spatial Fourier transforming property[9] of the convergent lens widely used in coherent optical computing, the complementary virtual Fourier transform capability of a divergent lens[10] is less widely known or used despite many attractive features. This is surprising since the power spectrum associated with the VFT is a phenomenon that is frequently observed in daily life when one happens to look at a distant point source such as a street light through a fine mesh screen or the fine fabric of transparent curtain material. The spectrum of the screen transmittance appears then as a virtual image in the plane of the point source.

The VFT concept of the divergent lens is easily derived from the Fourier transform expression of the convergent lens. Figure 1 illustrates the well known process of forming a real Fourier transform with a convergent lens. The object transparency, with complex transmittance $t(x_o, y_o)$, is placed at a distance d in front of a convergent lens of focal length F and illuminated with a normally incidnet collimated laser beam. The complex field amplitude of the wavefield in the back focal plane, the transform plane, is given by the well known formula

$$T(x,y) = \frac{j}{\lambda F} e^{-j\frac{k}{2F}\left[\left(1 - \frac{d}{F}\right)(x^2 + y^2)\right]}$$

$$\times \iint_{-\infty}^{\infty} t(x_o, y_o)\, e^{j\frac{k}{F}(x\,x_o + y\,y_o)}\, dx_o dy_o \qquad (1)$$

in which the integral is recognized as the two dimensional Fourier transform of the object transmittance. $T(x,y)$ becomes the exact Fourier transform of $t(x_o, y_o)$ when d = F that is when the object transparency is placed in the Front focal plane of the lens. The power spectrum associated with the transform is real and can be projected on a screen placed in the back focal plane. It is also well known that a scaled version of the transform can be obtained in the back focal plane by placing the object tranparency in the converging laser beam to the right of the lens[9].

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*Named after Lloyd Cross the originator of integral holography.

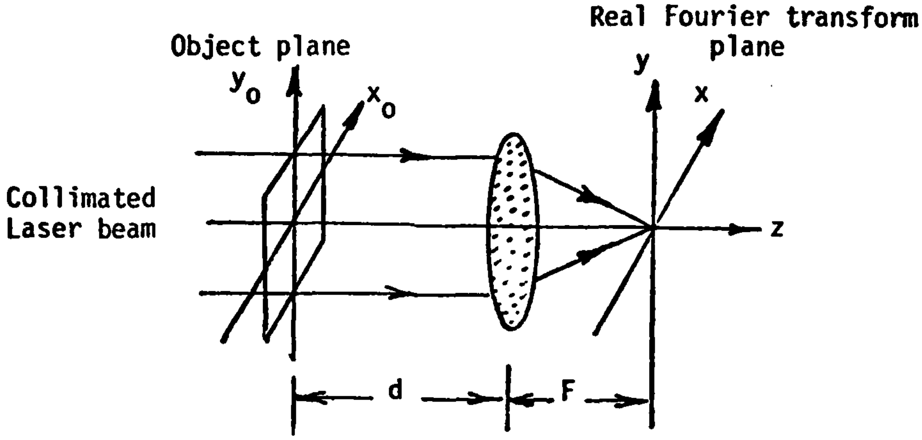


Fig. 1. Real Fourier transform formed with a convergent lens

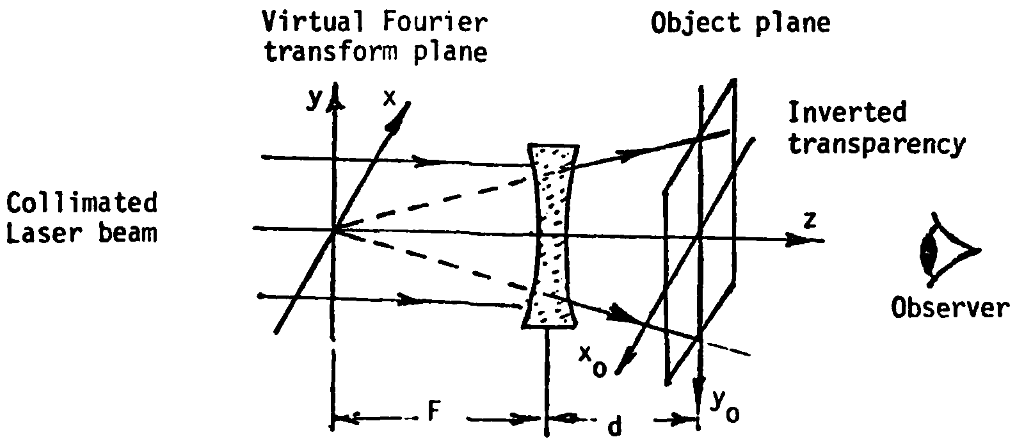


Fig. 2. Virtual Fourier transform formed with a divergent lens

Noting that eq. (1) does not change when we replace d by -d, F by -F, x_0 and y_0 by $-x_0$ and $-y_0$ respectively, we can arrive at the complementary VFT arrangement illustrated in Fig. 2. An inverted transparency $t(x_0,y_0)$ is placed now in the divergent coherent beam to the right of the divergent lens (of focal length -F) and a VFT given by eq. (1) is observed in the virtual focal plane of the lens. The same VFT can be seen by removing the divergent lens and replacing the laser beam with a point source placed at the origin of the VFT plane as depicted in Fig. 3. Thus a simple way of viewing the power spectrum associated with the VFT of a given diffracting screen (which is usually a Fourier transform hologram or a projection hologram of the type described above) is to hold the screen close to the eye and look through it at a distant bright point source. The point source used need not be derived from a laser. In fact it is preferable for safety purposes to use an LED or a spectrally filtered minute white light source such as a "grain-of-wheat" subminiature incandescent lamp or a miniature Christmas tree decorating lamp covered by a color or interference filter. This has the added advantage of furnishing a measure of control over the coherence properties of the wavefield impinging on the screen providing thereby a means for reducing coherent noise in the observed VFT and also, as will be discussed below, a means for coherent or noncoherent superposition of VFT's. As the distance of the point source from the diffracting screen is decreased in order to make it compatible with typical laboratory or optical bench dimensions, the size of the observed VFT decreased because of the change in the curvature of the wavefield illuminating the diffracting screen. To compensate for this effect it is necessary to reduce the size of the diffracting screen or transparency often to such a scale where viewing the VFT throught the small available aperture becomes difficult. To overcome this limitation the displacement property of the Fourier transform can be utilized. A composite transparency containing an ordered or random array of reduced replicas of the transmittance function $t(x_0,y_0)$ arranged side by side as illustrated in Fig. 4 is prepared. When such a composite transparency is viewed with the point source, the VFT's formed by the individual elements will overlap in the virtual Fourier plane. The VFT's are identical except for Linear phase dependence on x,y which depends in each VFT on the central position of each element in the composite transparency. This leads to a desirable noise averaging effect and the appearance of fine checkered texture in the image detail. All this leads to an enhancement of the quality of the observed power spectrum. Both coherent and noncoherent superposition of the overlapping VFT's is possible using this scheme by varying the coherence area of the wavefield illuminating the composite transparency. When the coherence area is roughly equal to the size of the individual elements of the composite transparency noncoherent superposition results, while a coherence area equal or greater than the size of the composite transparency would yield coherent superposition.

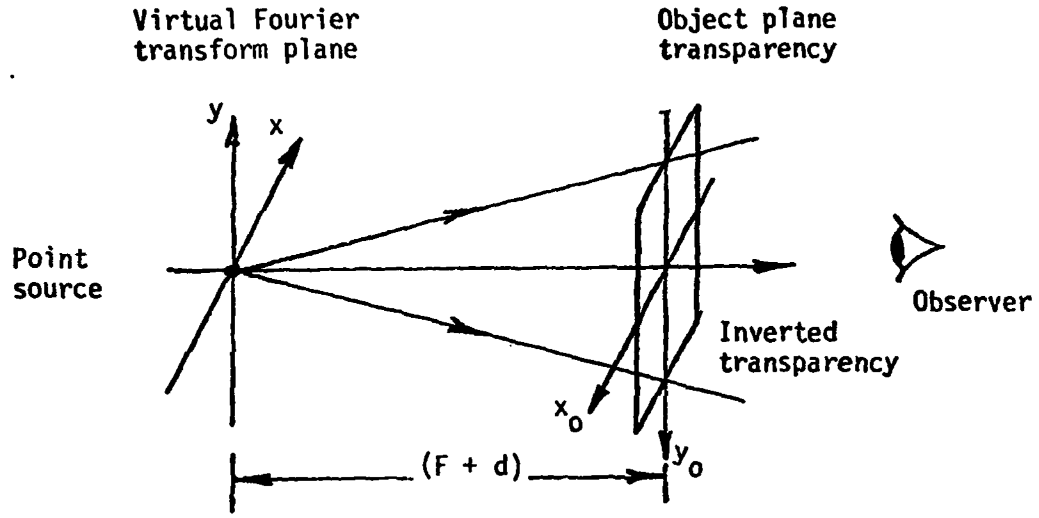


Fig. 3. Arrangement for viewing a virtual Fourier transform with a point source

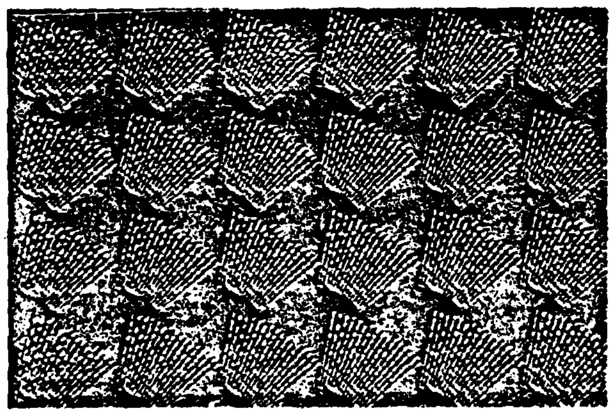


Fig. 4. A composite screen consisting of an ordered array of identical Fourier transform projection holograms.

THREE DIMENSIONAL DISPLAY

The VFT concept and the "weighted Fourier domain projection theorem" discussed above can be combined in an attractive scheme for the reconstruction and display of a 3-D image from a series of weighted projection holograms corresponding to different parallel slices through the object. The scheme is based on viewing a series of weighted projection holograms sequentially in the proper order of the occurance of their corresponding slices in the originalobject while displacing the point source axially for one hologram to next by an axial increment proportional to the spacings between adjacent object slices. In this fashion the reconstructed virtual images of the various slices are seen in depth at different VFT planes that are determined by the positions of the axially incremented point source. Repeated rapid execution of this procedure by displacing the point source back and forth leads the observer to see a virtual 3-D image tomographically in parallel slices or sections as he looks through the series of projection holograms passed rapidly, as in a motion picture film, infront of his eyes.

More specifically the scheme is based on preparing a series of N weighted Fourier domain projection holograms from the 3-D Fourier domain data $F(\bar{w})$ of a given object $f(\bar{r})$ as described in the preceeding sections. Each of the projection holograms would correspond to a different parallel slice through the object. A composite transparency similar to that shown in Fig. 4 is formed for each projection hologram. In fact Fig. 4 is an example of a computer generated composite hologram containing an array of identical weighted projection holograms corresponding to one slice of the test object shown in Fig. 5. The test object chosen consisted of eight point scatterers arranged as shown. The 3-D Fourier space of this test object was accessed in a computer simulation of wavelength diversity imaging as described in a companion paper in this volume*. The resulting computer generated Fourier space data manifold $F(\bar{w})$ was used to compute three weighted projection holograms corresponding to the three planes R_z'=1m,0,1m of Fig. 5 containing the three different distributions of point scatterers. A composite array such as that of Fig. 4 was formed and displayed by the computer for each of the three projection holograms, each was photographed yielding a set of three projection hologram composite transparencies. Copies of these were then mounted on a rotating wheel as shown in Fig. 6 (a) and viewed with an axially scanned point source. Four sets of transparency copies of these three composite projection holograms were mounted in the order 1,2,3,2,1,2 ... on the periphery of a rotating wheel as shown in Fig. 6 (a). The wheel is driven by a computer controlled stepper motor. The axially scanned point source was produced by scanning a focused laser beam back and forth on a length of fine nylon thread with the aid of a deflecting mirror mounted on the shaft of a second computer controlled stepper motor as shown in Fig. 6 (b). The laser and optical bench arrangement for forming the scanned focused beam appear in the background of Fig. 6 (a). The computer controlled steppers enable precise positioning of the secondary point source on the scattering thread in synchronism with the hologram

*See paper entitled "Holography, Wavelength Diversity Inverse Scattering" in this volume.

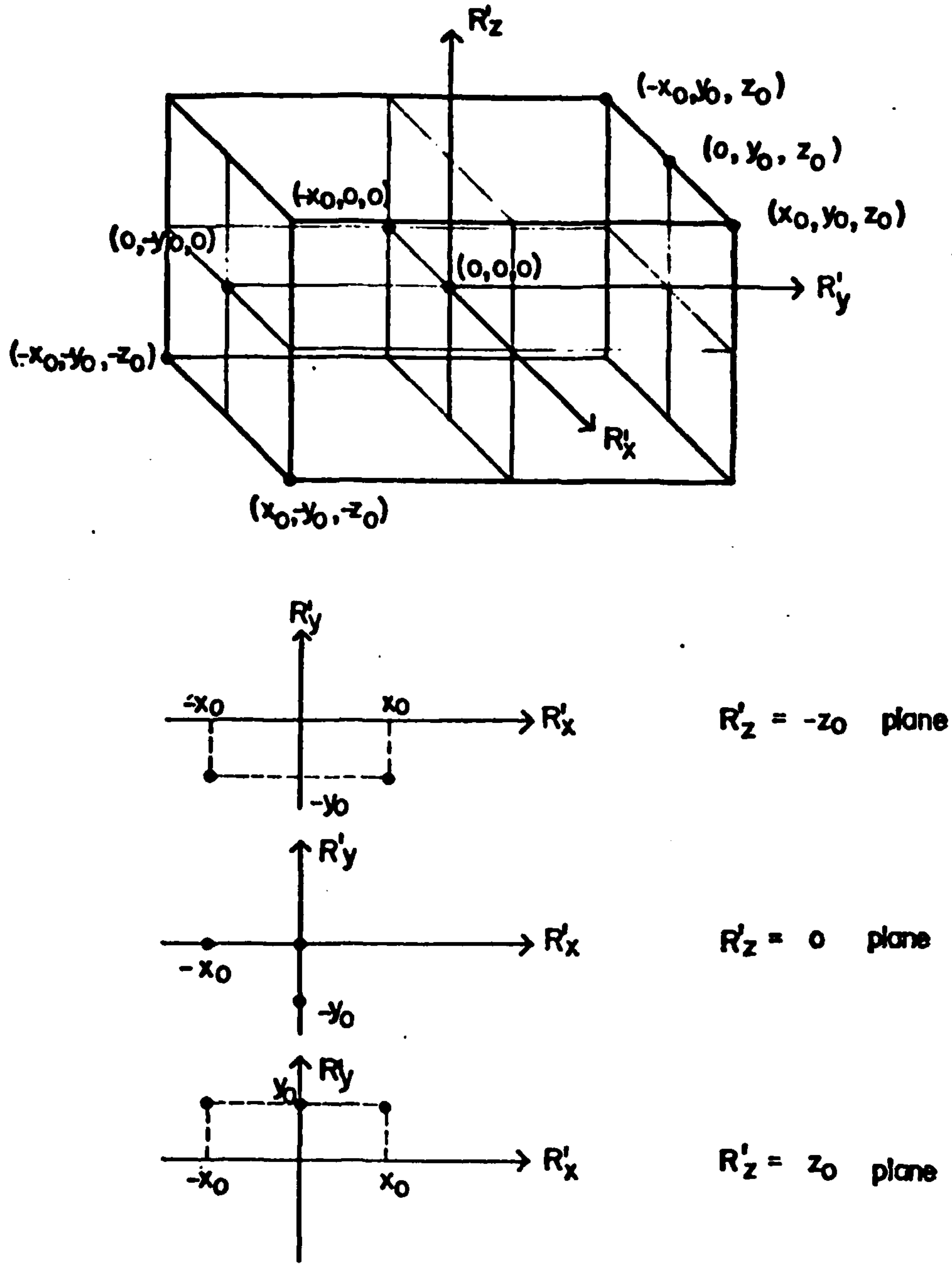
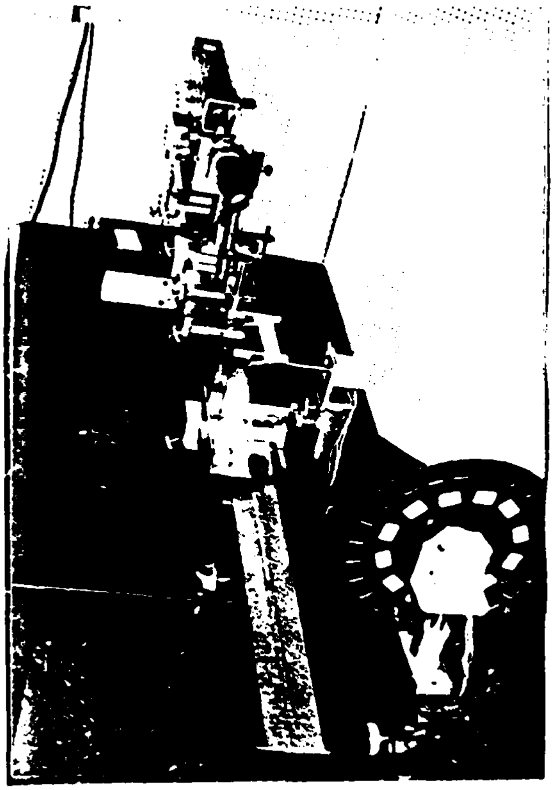
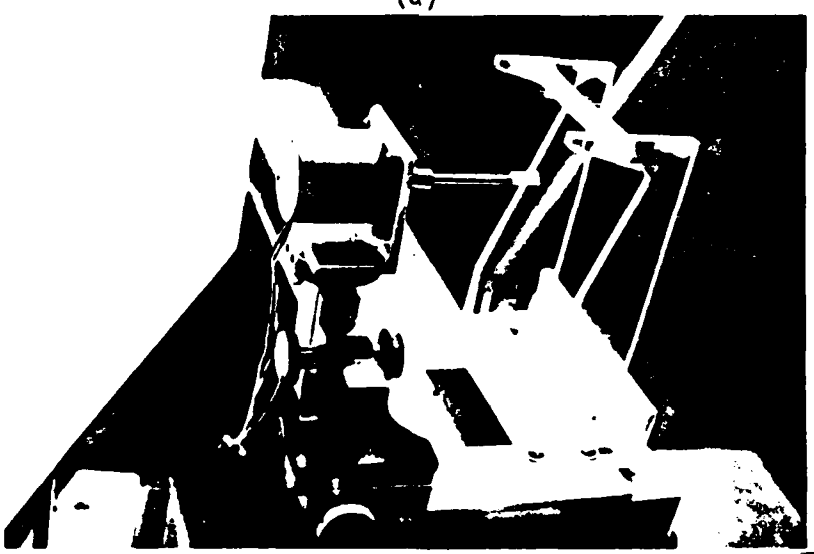


Fig. 5. A three-dimensional test object consisting of a set of eight point scatterers shown in isometric and R_x'-R_x' plane views at $R_z'=-z_o,0,z_o$. $x_o=y_o=z_o=100$ cm.

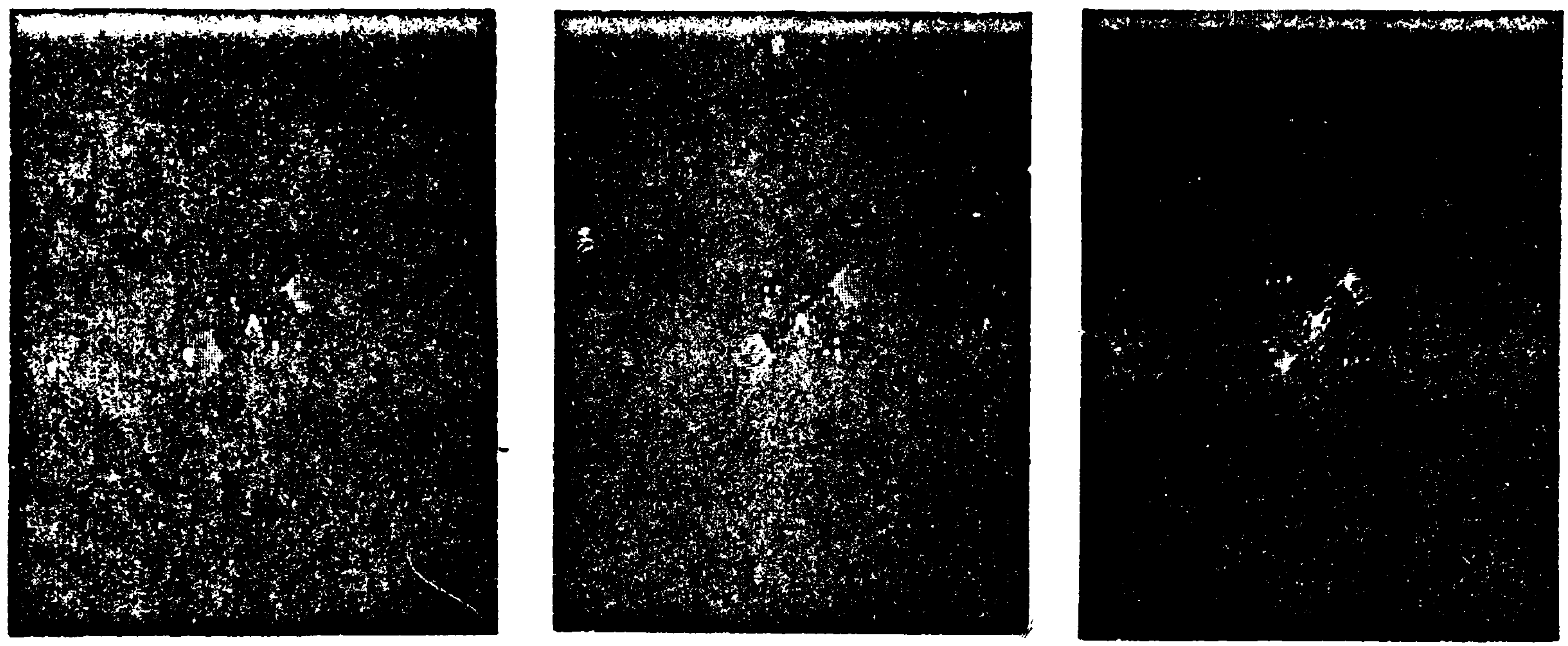


(a)



(b)

Fig. 6. Quasi real-time three-dimensional image reconstruction and tomographic display in successive slices from a series of projection holograms mounted on rotating wheel seen in fore-front of (a); Detail of laser scanner used to produce linearly scanned point source is shown in (b).



(a) (b) (c)

Fig. 7. Photographs of three slices of the virtual 3-D image of the test object of Fig. 5 obtained by photographing the VFT's formed from corresponding Fourier domain projection holograms.

being viewed so that the VFTs are formed in their proper planes. A viewer looking at the axially displaced point source through each transparency mounted on the wheel as it passes infront of his eye will see a 3-D virtual image. Photographs of the three virtual images seen by an observer in this fashion are shown in Fig. 7. An opto-digital scheme for rapid real-time implementation of the procedure realized above is shown in Fig. 8. This scheme, presently under study, utilizes a rapid recyclable spatial light modulator (SLM) such as the Itek PROM in order to form VFT's of the projection holograms displayed by the computer in real-time.

CONCLUSIONS

We have presented the basic principles of tomographic 3-D image display based on Fourier domain projection theorems. One possible implementation of the principle using the virtual Fourier transform and a series Fourier domain projection holograms has been described. There are several advantages for using the VFT rather than the real Fourier transform (RFT), the most important of which is the ease with which the position of the VFT plane can be moved axially by simply moving the position of the reconstruction point source. The VFT approach was adopted in the present study because it is much easier to move a point source rapidly than to move the display screen needed in the RFT approach. Furthermore focusing in the VFT approach is carried out by the observer while in the RFT approach it must be performed by the system. Other attractive features of the VFT are:

(a) Simplicity - enables direct viewing of the power spectrum of a transparency or a hologram with a variety of simple point sources.

(b) The scale of the observed VFT can be easily altered by changing the distance between the projection hologram transparency and the reconstruction point source.

(c) Lower speckle noise and therefore higher reconstructed image quality can be attained by using nonlaser point sources in the reconstruction such as LED or miniature spectrally filtered incandescent lamps. Further reduction in speckle noise occurs when an array of the projection hologram rather than a single hologram is used and when the hologram is slightly vibrated or is in motion because of a noise averaging effect.

(d) Coherent and noncoherent superposition of VFT's is possible by altering the coherence area of the reconstruction wavelfield.

(e) Because of the Fourier transform nature of the projection holograms utilized, the resolution requirements from the storage medium (photographic film or the CRT/SLM system of Fig. 8) are much lower than would be needed in the recording of a Fresnel hologram of the object as a means of 3-D image display. The 3-D image detail contained in the single Fresnel hologram is now distributed over a series of lower resolution projection holograms which are used to form the 3-D image sequentially in time in individual slices.

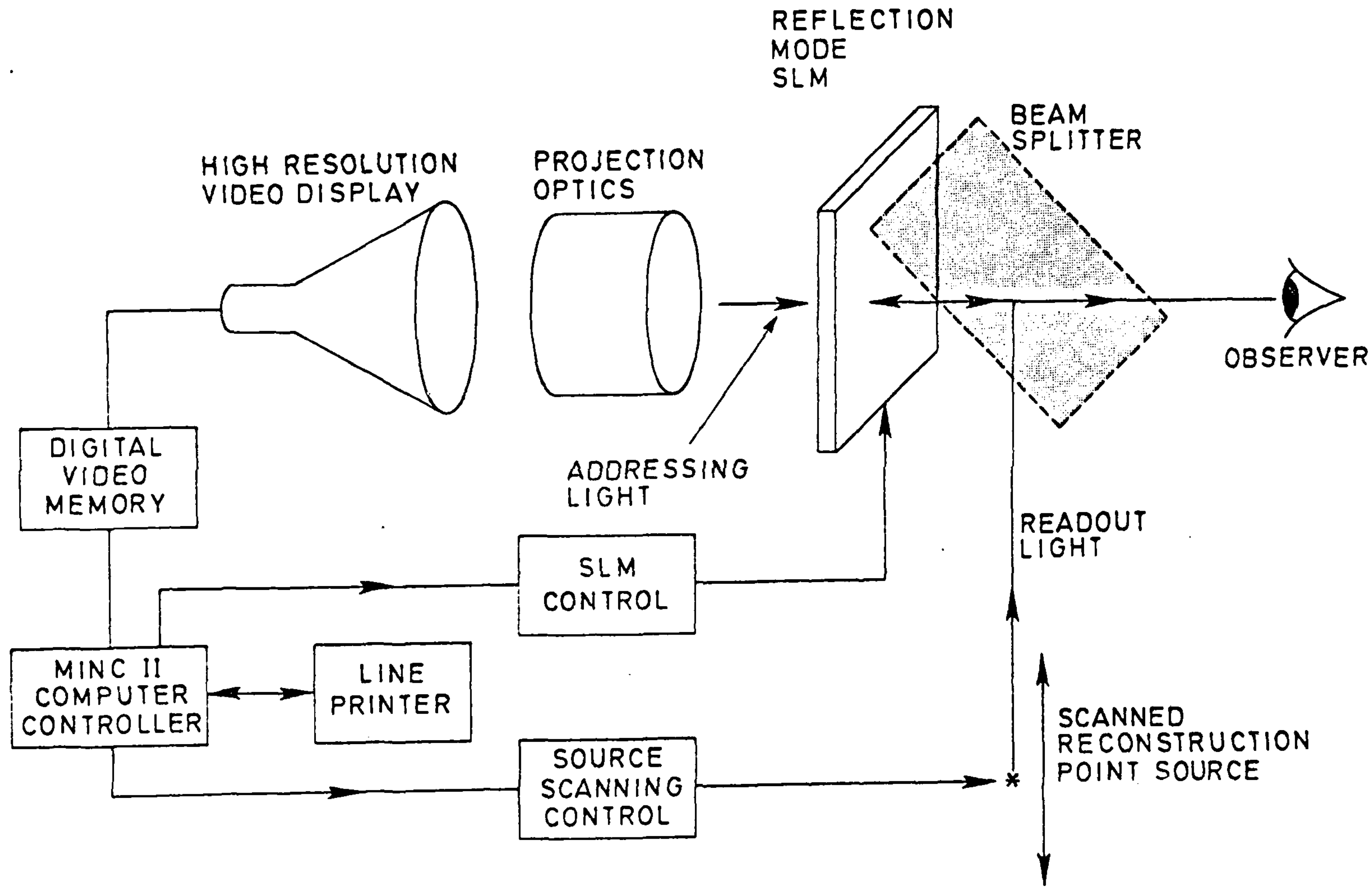


Fig. 8. Opto-digital scheme for the reconstruction and display of 3-D images using a recyclable spatial light modulator and a point source to view the VFT in real-time.

(f) Because 3-D image reconstruction is tomographic (in separate slices) there is no interference between the wavefields forming the various slices.

(g) Permits other forms of 3-D image display involving spatial or angular multiplexing in a fashion similar to integral holography.

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APPENDIX IV

AN AUTOMATED FREQUENCY RESPONSE AND RADAR CROSS-SECTION MEASUREMENT FACILITY FOR MICROWAVE IMAGING

UNIVERSITY OF PENNSYLVANIA

THE MOORE SCHOOL OF ELECTRICAL ENGINEERING

AN AUTOMATED FREQUENCY RESPONSE AND RADAR CROSS-SECTION MEASUREMENT FACILITY FOR MICROWAVE IMAGING

CHARLES L. WERNER

Presented to the faculty of the Moore School of Electrical Engineering (Department of Electrical Engineering & Science) in partial fulfillment of the requirements for the degree of Master of Science in Engineering.

Philadelphia, Pennsylvania

May 1980

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THE MOORE SCHOOL OF ELECTRICAL ENGINEERING

AN AUTOMATED FREQUENCY RESPONSE AND RADAR CROSS-SECTION MEASUREMENT FACILITY FOR MICROWAVE IMAGING

ABSTRACT

This thesis investigates the development of a broadband microwave holographic imaging facility. Different methods for the correction of microwave target scatter data are discussed and implemented. A minicomputer automates all system functions including data acquisition, storage, calculation, and graphic display. The effects of range phase shift on holographic frequency diversity imaging is considered and techniques for the removal of this phase shift in a laboratory environment . The frequency dependent backscatter of several test targets is derived analytically and simulations done of the corresponding holograms. These holograms are compared to those measured experimentally. Finally both simulated and experimental holograms are optically reconstructed to yield target images using optical Fourier transforms and shown to be in excellent agreement.

Degree: Master of Science in Engineering for graduate work in electrical Engineering and Science

Date: May 1980

Charles L. Werner
Author

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TABLE OF CONTENTS

I INTRODUCTION

Frequency diversity imaging has been under study at the Electro-Optics and Microwave Optics laboratory of the Moore School Graduate Research Center.[1],[2],[3],[4] This study has established the theoretic feasibility of imaging objects by means of their multiaspect frequency response. For the purpose of experimentally studying frequency diversity imaging, an experimental measurement system has been assembled and installed in the Moore School anechoic chamber. In this thesis we will describe the automation of this measurement system and characterize its peroformance in the measurement of complex field amplitudes of scattered fields. A system block diagram fig.1.1, shows the major system components. The central element is the DEC MINC LSI 11/2 minicomputer. This computer performs several important functions. The MINC controls laboratory instrumentation via the IEEE-488 bus protocol standard. This allows the Hewlett-Packard 8620C microwave sweeper to be precisely tuned to any frequency in the 2.0 to 18.0 GHz range (fig.1.2). The computer collects data from the HP 8410B network analyzer through the four analog input channels available. These analog values are proportional to the amplitude in db and phase in the range ($-\pi$) to ($+\pi$) radians relative to the reference signal supplied to the network analyzer. The computer stores Experimental data on floppy discs. The available storage capacity is large, over 500,000 measurement pairs of complex field amplitude and

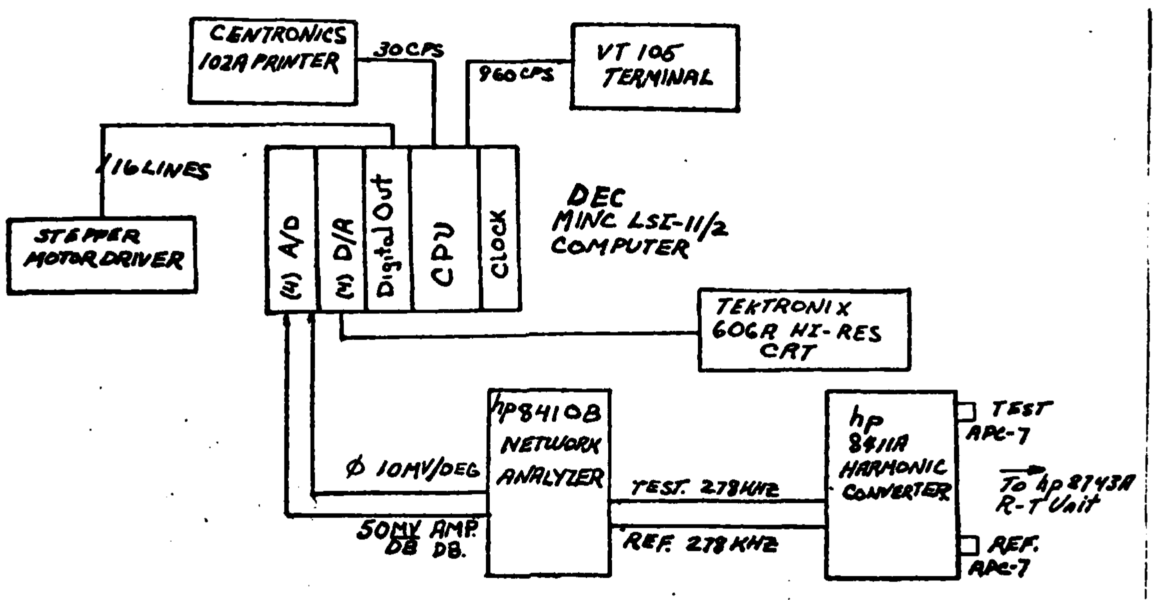

Fig. 1.1 System block diagram.

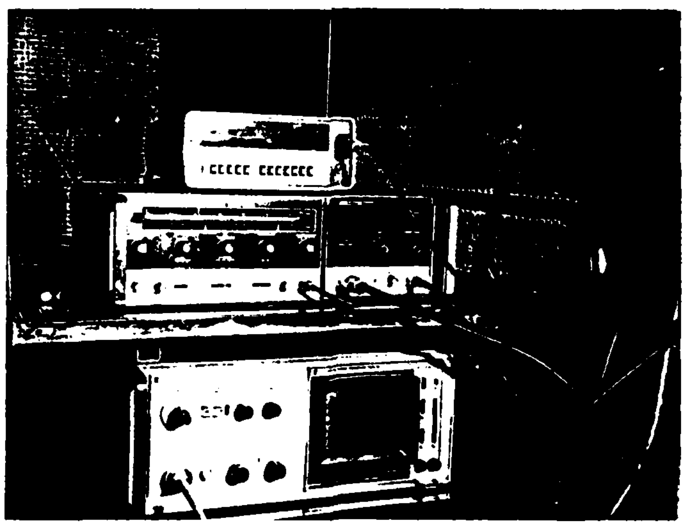

Fig. 1.2 HP 8620C microwave sweeper and HP 1410B network analyzer.

phase may be stored on a single disc. This data can be accessed for both processing and display on a Tektronix 606A high resolution CRT monitor. The disc system allows the MINC to operate under a sophisticated software system, DEC RT-11 V3.0B permitting programing in MINC BASIC,FORTRAN IV, and MACRO languages.

The processing capability of the system allows the removal of system response errors due to anechoic chamber clutter,antenna cross-coupling and receiver channel characteristics. The data may be processed for target range calculations and the removal of the phase shift due to the target range. In addition the collected data may be filtered to improve imaging and finally displayed on a high resolution Tektronix 606A X-Y CRT monitor using the MINC system D/A converter module.

The second part of this thesis will describe the simulation and actual operation of a holographic radar system verifying the theory of frequency diversity imaging. This is done using the system described in the first section. The scattering of various targets is derived and holograms using these results are generated for comparison with experimental data. Finally a system for the experimental measurement of the scattering for these targets is outlined and the results from this system compared to theory.

II SYSTEM OPERATION AND ERROR REMOVAL

This chapter will cover the operation of the microwave backscatter data aquisition system. This will include actual interfacing information and an analysis of the types of errors encountered when making microwave measurements. The error correction techniques developed are later used in the experimental verification of the frequency diversity imaging theory.[4]

2.1 Microwave sweeper operation

The first task in the development of an automated data acquisition system is the implementation of a data communications link between the intelligent controller and instrumentation. The IEEE-488 bus protocol is utilized in this application for the transfer of data to the Hewlett-Packard 8620C microwave sweeper from the MINC LSI 11/2 computer. This bus is a high speed 8 bit wide bidirectional data path with 5 additional lines dedicated to control. Data is transferred in ASCII format over the bus. For example the number 1 is transmitted as the ASCI code for the character '1'. Certain sequences of characters make the sweeper perform different functions or enter different modes of operation via its IEEE-488 interface.

In order to set the frequency of the sweeper a number must be sent to the IEEE-488 interface in the range 1-10000. Each sweeper frequency band has been split into 10000 frequency points. The frequency of operation is controlled

by an internal analog voltage that varies between 0.0 and 10.0 volts. A D/A converter on the 8620C IEEE-488 interface changes the data transmitted from the MINC into the frequency controlling voltage. The correspondence between voltage and output frequency is essentially linear. In order to obtain the interpolating function for frequency versus control voltage; a microwave frequency counter was used to measure the voltage-frequency characteristic function. Using the MINC-BASIC program CALAB.BAS a least squares fit for both linear and quadratic functions was made on the frequency vs voltage data. This type of program is used for determining the best polynomial fit to the frequency-voltage characteristic of the sweeper. Sample output and program listings are in appendix I along with an explanation of program operation. The results from this work indicate that the quadratic fit was statistically superior for all bands on the microwave sweeper. The FORTRAN subroutine SWEEP was written which utilizes the quadratic interpolation polynomial for each of the four bands of the 8620C. This subroutine automatically calculates the control voltage and band to generate any frequency in the 2-18 GHz range and transmits the appropriate commands over the IEEE-488 bus. The variance of the frequency setting using the quadratic fit for the three bands are as follows: .6 MHz in the 2.0-6.3 GHz band; 1.2 MHz in the 6.3-12.0 GHZ band; and 1.6 MHZ in the 12.0-18.0 GHz band. For higher accuracy the sweeper may be phase

locked to the reference in a locking frequency counter yielding very high accuracy as precise as the frequency reference itself. The EIP 371 locking counter may be used in this application to lock the HP 8620C sweep oscillator to the correct frequency once it is within 20 MHz of the desired frequency. The auxiliary output of the HP 8620C supplies a sample of the signal generated by the fundamental 2.0-6.3 GHz oscillator module within the sweeper to the locking counter. Sweeper output on higher bands is this fundamental multiplied by a factor of 2 or 3 for the 6.3-12.0 and 12.0-18.00 GHz bands respectively. For example the locking frequency for a 10.0 GHz sweeper output on band 2 would be 5.0 GHZ. In operation, subroutine SWEEP will set the frequency of the sweeper within 2.0 MHz of the desired frequency and subroutine SLOCK will be called to calculate the locking frequency; lock the HP 8620C and return to the main calling routine when lock will have occurred. Lock time varies from .1 to 3 seconds and resolution is 100 KHZ. These subroutines are called whenever the sweeper must be set to a particular frequency or the sweeper must be placed in or be released from computer control.

2.2 Network analyzer-computer interface

The Hewlett-Packard 8410B network analyzer is the focus of the measurement capabilities of the microwave measurement system. It can make vector(amplitude and phase) measurements in the (.1-18.0)GHz range. The range of amplitude measurement is 80 db and phase may be measured

modulo (2π). The system reference signal is fed from a 20db directional coupler to the HP8411A harmonic converter sampling head of the network analyzer. This reference is compared to the backscatter from the illuminated target; both in amplitude and phase. The reference signal amplitude is kept constant by leveling the sweeper with a feedback signal derived from its amplified output by means of a crystal detector. This allows the sweeper-TWT (Traveling Wave Tube) system to yield nearly constant output in the (2.0-16.5) GHz range; see fig.2.1. TWT power output is on the order of 1 watt over these frequencies.

The complex field amplitude measurements are available as analog voltages from the back panel of the 8410B. The outputs are proportional to amplitude and phase: 25 MV/db and 10 MV/DEGREE These values are digitized by the MINC using its built in analog to digital conversion channels. The MINC A/D converters digitize voltages lying in the range of -5.12 to +5.12 volts to the range of 0-4096 yielding 12 bit resolution. If the signal is corrupted by noise; the user has the option of employing signal averaging to cancel the effects of noise uncorrelated to the received signal.

A difficulty encountered when measuring phase angle modulo (2π) occurs when the phase is close to ($+\pi$) or ($-\pi$). At this point a small change in the signal phase may cause the phase to flip between these two equivalent extremes rapidly. If a data sample is taken close to ($+\pi$) or ($-\pi$) it may be in transition between them and therefore incorrect.

Since such points occur infrequently in a typical measurement they may be ignored. ;their presence does not seriously hinder any holographic imaging due to the inherent redundancy and therefore noise immunity of the holographic reconstruction process.[5] If it is desired that these points be identified and removed it is necessary to estimate the mean and variance of the samples taken at each frequency point. At frequencies where the phase is flipping between ($+\pi$) and ($-\pi$), the variance will be much larger than at other frequencies. The mean of the samples when this is occurring will be near zero. Hence to resolve the ambiguity problem it is necessary to decide if the variance exceeds a predetermined threshold when the mean in the neighborhood of zero. Two FORTRAN subroutines PHAMP and PHAMP2 which implement these algorithms are listed in appendix I.

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2.3 Implementation of the data aquisition system

In an experimental environment it is important to be aware of the various types of errors inherent in the equipment and the experimental procedure adopted. Conditions and equipment always vary from theoretical ideals. A clear understanding of the error removal process leads to the development of practical implementations of theoretical concepts and enhancement of measurement accuracy unattainable otherwise.

Errors in complex field amplitude measurement may be caused by several factors. These may be grouped into two categories. Errors caused by the instruments themselves fall into the first class. Such factors as measurement variations caused by electronic noise, ,inaccurate A/D and logarithmic conversions, and inaccuracy and instability in the microwave source make up this category. The second group of errors is caused by the test set,antennas , cables, connectors, amplifier, and room clutter. All these factors interact with each other in the microwave region and are the significant cause of error in microwave measurements. Little can be done about the first class of errors since they are inherent in the characteristics of the equipment used. The second group of errors can be removed through the use of automated measurement of system parameters in the frequency range of interest. These errors can be removed form any measurements of scattering objects by digital processing and the results stored for later recall. This

essentially provides an automated and improved version of the conventional two antenna radar cross-section measurement technique [6] ;in which a microwave bridge is balanced in the absence of the target and the degree of imbalance is measured when the target is introduced into the microwave field.

Let us look at the first class of errors more closely since these errors will set the ultimate performance limits on the system. The characteristics of the signal source are important in this regard. In this case the signal source is a Hewlett-Packard 8620C microwave sweeper. Since the sweeper is not phase locked frequency and stability problems exist. The carrier also has significant FM noise which appears as phase noise in the scattered signal. The phase shift of the scattered scattered signal as a function of frequency for small frequency variations is given by:

$$\Delta\Theta = \Delta k \cdot R \tag{2.1}$$

where $k=(2\pi/\lambda)$ and R is the path length. For R greater than a few tens of meters ,the FM noise on the signal source causes measurable variations in the phase of the scattered signal. The stability of a synthesizer is required for the implementation of a holographic radar system when target ranges are in terms of kilometers.

Another limit on the ultimate accuracy of the system is the resolution of the A/D conversions and the accuracy of the network analyzer. Given the 2.2MV resolution of the MINC A/D converter and the network analyzer analog output of

50 MV/db, the system can resolve .048 db steps. This resolution limit restricts the minimum signal to system error ratio. If the error signal consisting of clutter, antenna coupling, system directivity and noise exceeds the scattered target signal the resolution of the target signal suffers. For example, if the system error signal and target scattered signal are of equal intensity, then a 1 db change in the scattered signal causes a .53 db change in the total received signal vector. When the system error is 13 db above the scattered signal it becomes impossible to resolve a 1 db change in the target signal given the resolution capabilities of the system. This difficulty is further compounded by errors in the network analyzer. These too are amplified when the clutter exceeds the target scatter signal. In fig.2.1 is a plot of the minimum system resolution in order to detect a 1 db change in the target return signal versus the system error signal to scattered signal level in db. In fig.2.2 is plotted the target signal resolution versus the noise to signal level in db. When the system error is 20 db below the target signal then the resolution of the target scatter signal is very close to the ultimate resolution, .048db. Clutter is the component of the received signal not scattered by the target but that signal that is the result of coupling between antennas and signal scattered by the anechoic chamber walls. As the clutter/signal ratio increases the target scatter signal resolution decreases exponentially. Clutter may be reduced

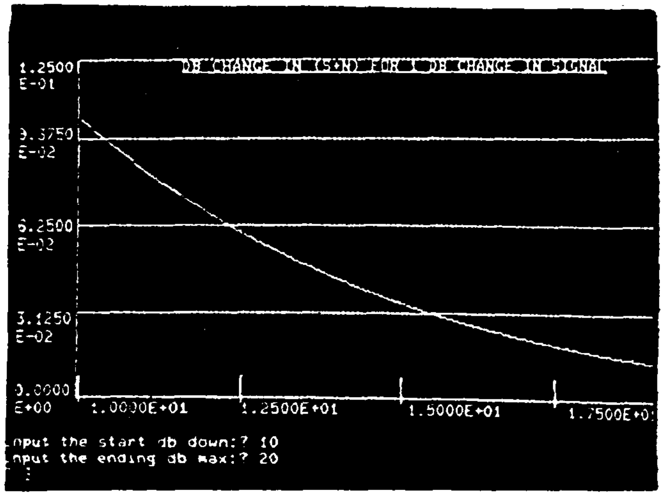


Fig. 2.1 The required resolution in db for a data acquisition system to detect a 1 db change in the desired signal vs. signal/error -signal ratio.

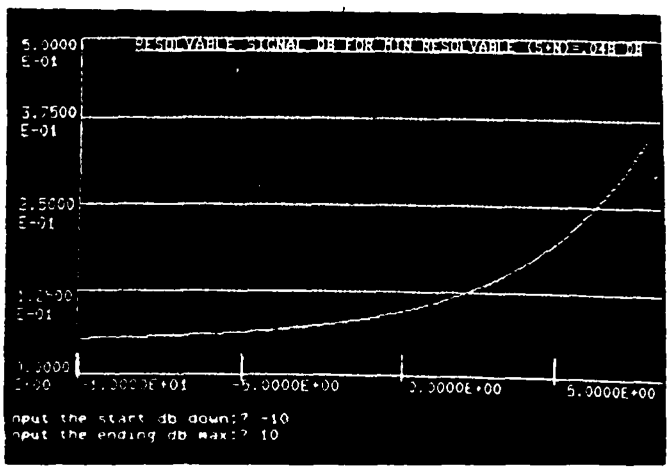


Fig. 2.2 Minimum change in desired signal level detectable versus signal/error signal level given .048 db system data acquisiton resolution.

by improving the isolation between the transmitter and receiving antennas with the introduction of absorbing foam panels such as Emerson and Cummings' Ecosorb panels between the antennas.

2.4 System error correction

Turning next to the second class of errors; those directly measurable and therefore removable; define the following quantities which are functions of frequency :

I(f) -- Isolation of reference to test channels

T(f) -- Transfer characteristic of system

A(f) -- Attenuator characteristic

A1(f)-- Antenna system characteristic

S(f) -- Corrected backscatter for target

C1(f)-- Uncorrected antenna clutter and coupling

C2(f)-- Corrected antenna clutter and cross-coupling (uncorrected for antenna system response)

C(f) -- Corrected antenna clutter and coupling

R1(f)-- uncorrected reference target backscatter

R2(f)-- Corrected reference target data (uncorrected for antenna system response)

R(f) -- Corrected reference target data

Several possible techniques exist for the removal of system errors. The particular technique is dependent on the relative signal levels involved, the accuracy desired, ease of implementation, and computational speed. The first technique described here is similar to that used by Weir et al .[7]

The first step in the correction procedure measures the transfer function of an attenuator A(f) as a function of frequency. The equipment setup for this procedure is shown in fig. 2.3. The two ports of the reflection-transmission unit connected through a precision HP 11605A flexible coaxial arm. The MINC then steps the sweeper to a number of frequency points and stores the system response (log amplitude and phase vs. frequency) in memory. When this completed the attenuator is placed in series with the arm and another set of measurements is made at the same frequency points as before. the system response characteristic is subtracted from the combined attenuator plus system response measurement made on the second sweep. An example of this procedure is shown in fig 2.4. Computer subroutine PAD performs this operation. It is listed in appendix I along with all other computer program listings and output pertaining to system response measurement and removal.

The next step in the calibration process is measurement of the reference to test channel isolation I(f). This characteristic is dependent on the directivity of the network analyzer harmonic converter,and the reflection transmission unit. For the Hewlett-Packard 8411A harmonic converter the isolation is greater that 50 db. In this measurement the ports of the reflection-transmission unit are terminated in the cables used for the later target scatter measurement. These coaxial cables are terminated in

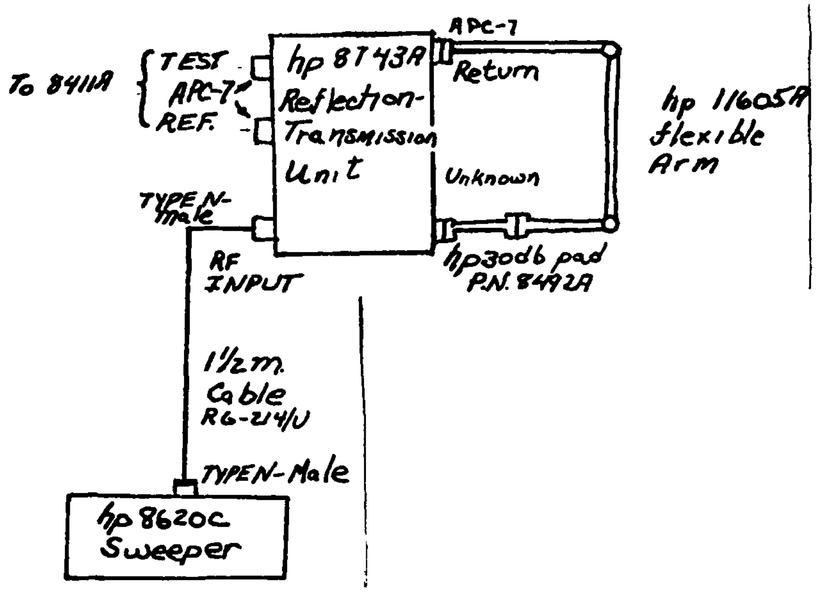


Fig. 2.3 Equipment setup for attenuator measurement.

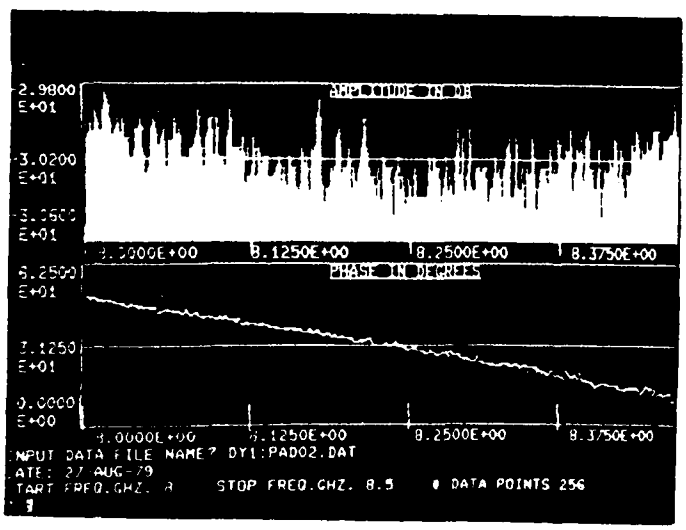


Fig. 2.4 30 db attenuator characteristic for 8.0-8.5 GHz.

50 ohm resistive loads as shown in fig.2.5. The results of a typical run are shown in fig.2.6. Computer subroutine IST automates this stage in the correction procedure. As can be seen the coupled signal is well in the noise of the system and would not affect later scatter data. If the isolation effect is ignored later calculation would be simplified greatly; but is included here to be consistent with the procedure outlined in the literature.[7]

The next stage in generating the data for correction of scatter data is measurement of the system transfer function T(f). This consists of the characteristics of the traveling wave tube amplifier,system cables and connectors. This is done by connecting the cable from the transmitting antenna to the receiving antenna cable in fig.2.6 and placing the 30 db attenuator characterized previously in the line to avoid damage to the harmonic converter. The raw measurement MT(f) is a combination of several factors:

$$MT(f)=T(f)*A(f)+I(f) \tag{2.2}$$

Solving for T(f):

$$T(f)=(MT(f)-I(f))/A(f) \tag{2.2a}$$

The equipment setup for this procedure is shown in fig 2.7 and typical uncorrected and corrected transfer function data in fig.2.8 and 2.9.

Measurement of the antenna cross-coupling and room clutter is the next step in the correction process. In this procedure shown in fig.2.7b, the target is removed from the anechoic chamber and the antennas pointed to the target

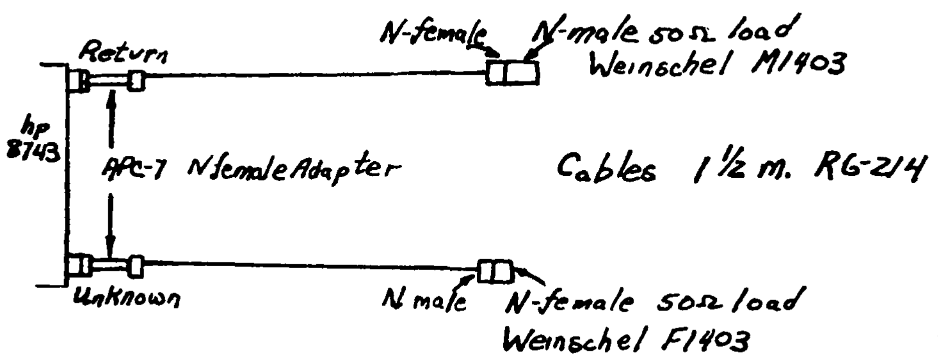


Fig. 2.5 System configuration for measuring isolation between reference and unknown ports.

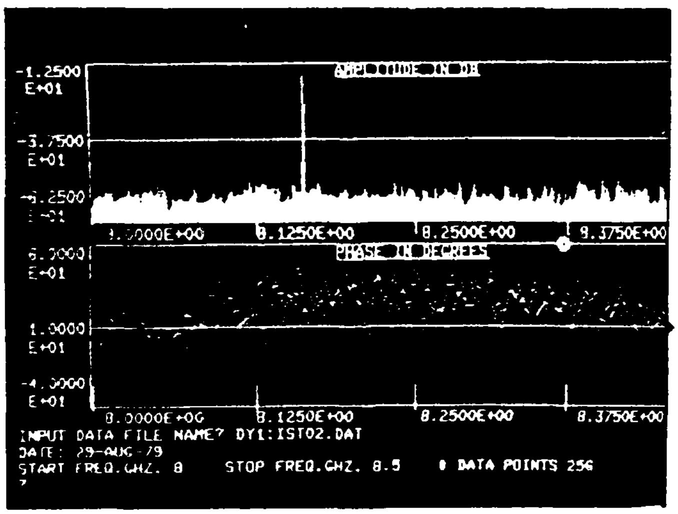
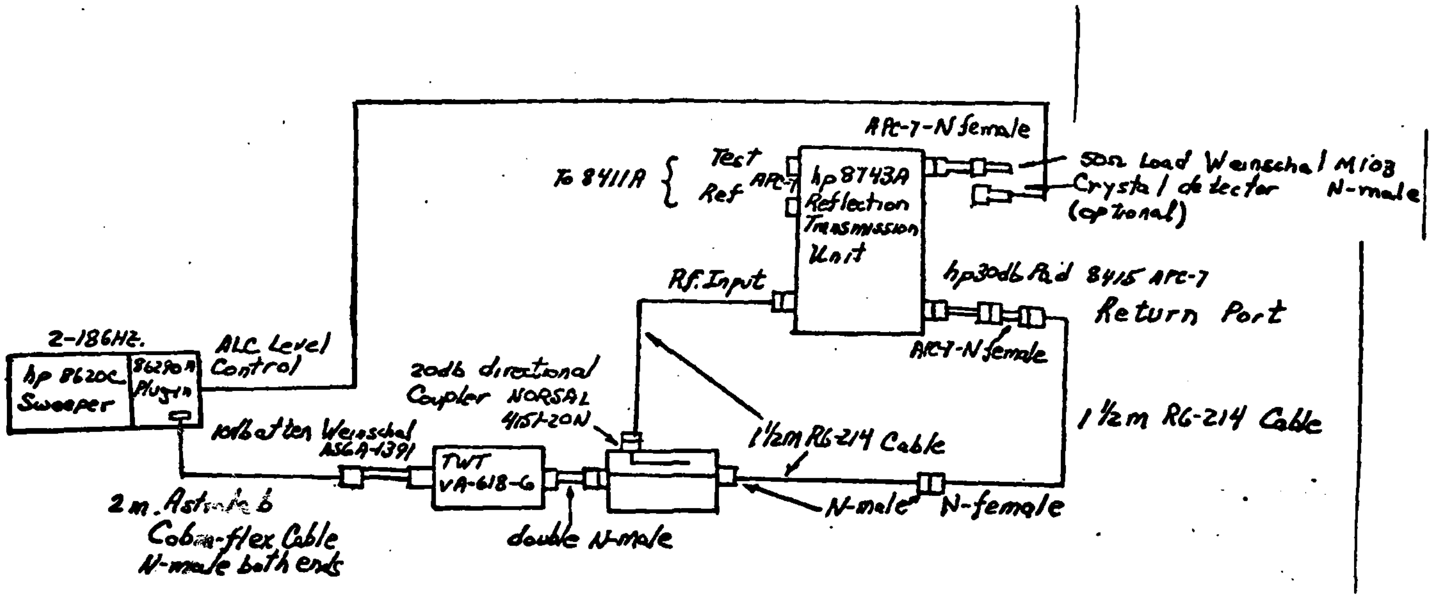
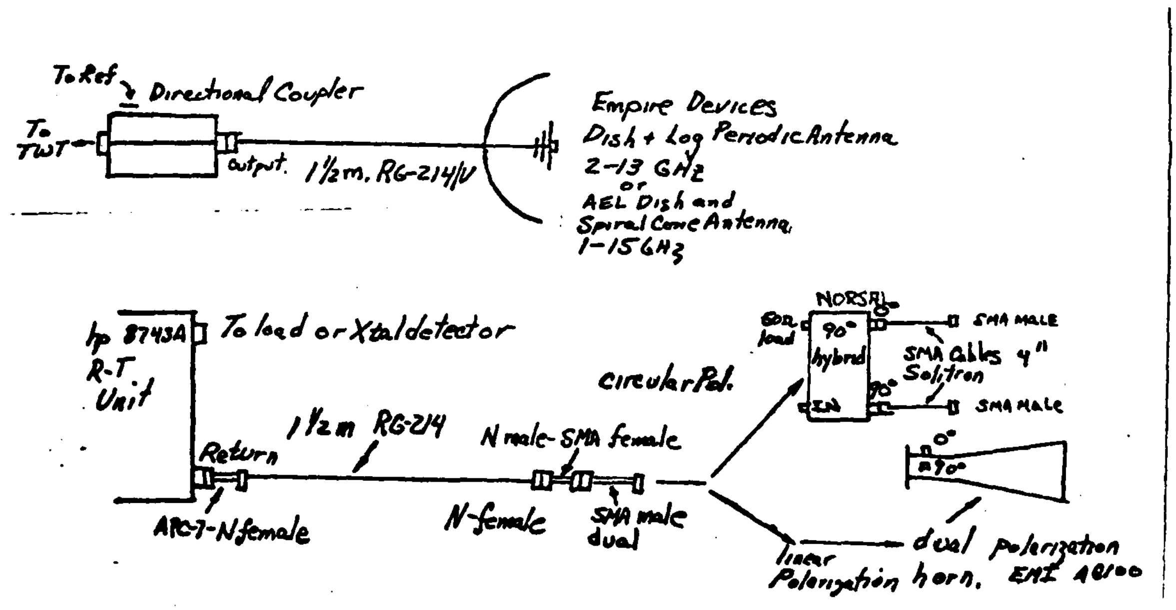


Fig. 2.6 Isolation between ports of reflection-transmission unit; 8.0-8.5 GHz.

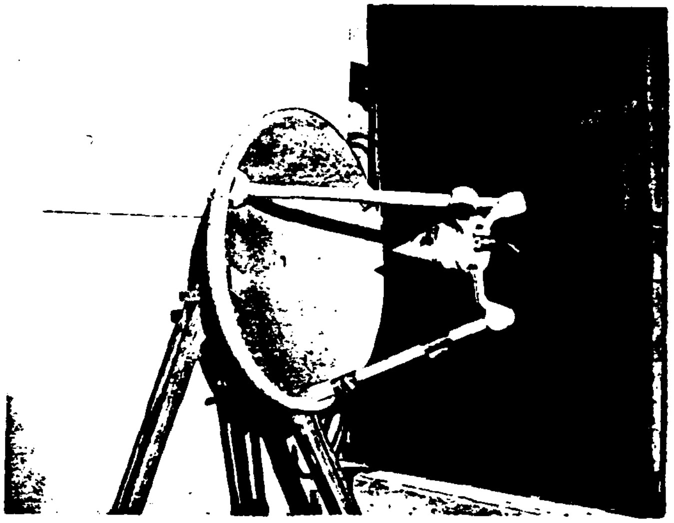


(a)

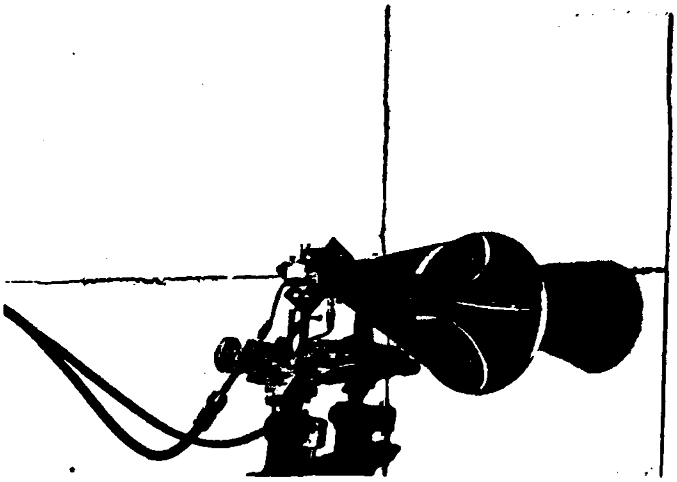


(b)

Fig. 2.7 a) System configuration for transfer characteristic measurement. b) Connection to antennas for scattering and clutter measurement. c) Transmitting antenna with spiral AEL antenna and parabolic dish. d) Receiving dual polarization horn ; EMI A6100 with Norsal 90 hybrid.



(C)



(d)

Fig. 2.7 (contd.) a) system configuration for transfer characteristic measurement. b) Connection to antennas for scattering and clutter measurement c) Transmitting antenna with spiral AEL antenna and parabolic dish. d) Receiving dual polariztion horn; EMI A6100 with Norsal 90 hybrid.

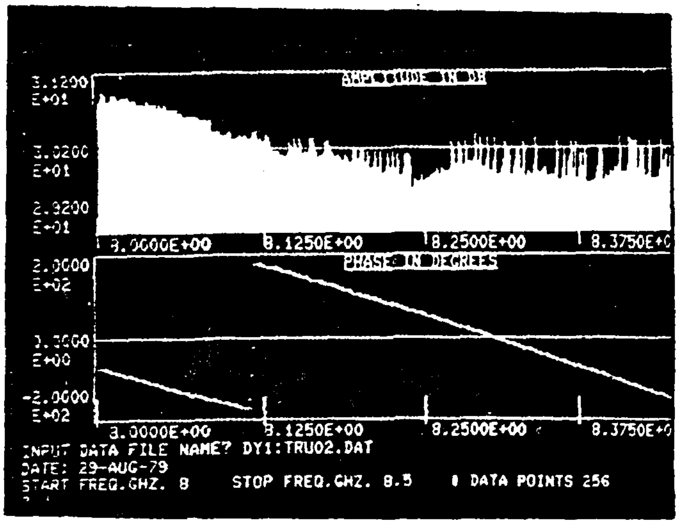


Fig. 2.8 Uncorrected transfer characteristic of system; 8.0-8.5 GHz.

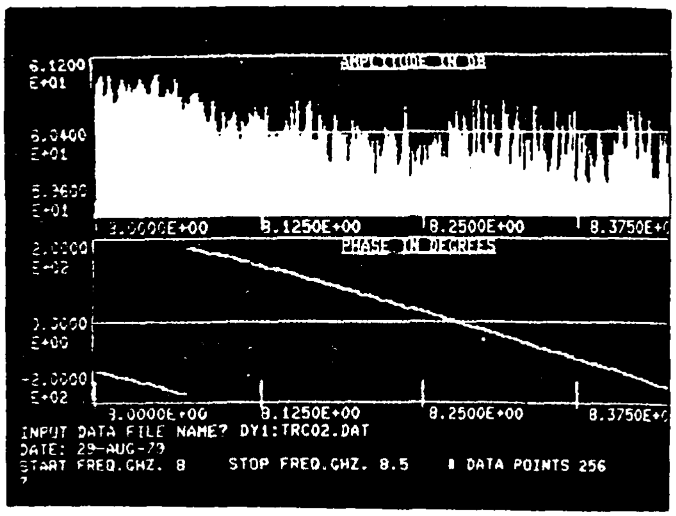


Fig. 2.9 Transfer characteristic corrected for attenuator response; 8.0-8.5 GHz.

location. A high gain parabolic dish antenna is used for illumination of the target since the narrow beam pattern of the antenna places most of the radiated power on the target area. A smaller dual polarization horn is used for receiving in order to sample a small area of the scattered field. The uncorrected clutter C1(f) is given by:

$$C1(f)=C2(f)*T(f)+I(f) \tag{2.3}$$

Solving for the corrected clutter and coupling:

$$C2(f)=(C1(f)-I(f))/T(f) \tag{2.3a}$$

Subroutine ANTEN does the system clutter and coupling removal. Examples of the uncorrected and corrected clutter C1(f) and C2(f) are shown in figs.2.10 and 2.11. The corrected clutter represents the actual signal reflected from the anechoic chamber walls and that signal coupled between the antennas with the system response removed.

These subroutines: PAD,IST,TRANS, and ANTEN, were combined into a program SYSRES. Data from each of these subroutines may be stored on disc for later recall or display. Theoretically if the system is not disturbed then the system response will remain constant. Then only the target data need be recorded in any run for a new corrected backscatter measurement.

The transfer function of the system and the range clutter- antenna cross coupling data are utilized the the next step of the error correction process. A reference object of known constant cross section is measured and the result stored. This data includes all the errors previously

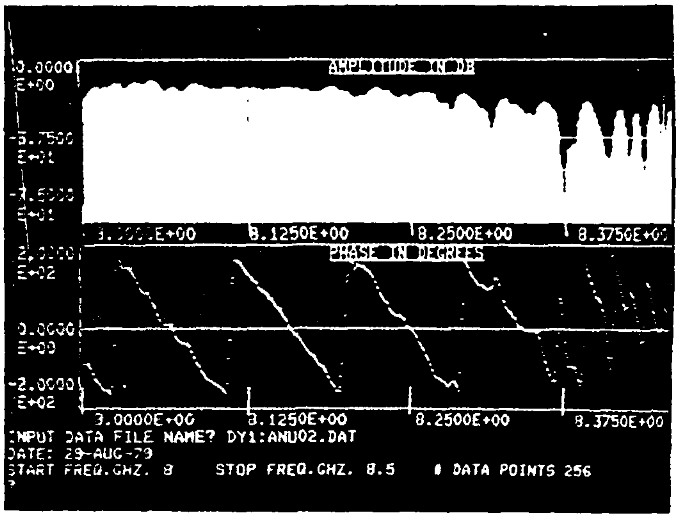


Fig. 2.10 Uncorrected system clutter; 8.0-8.5 GHz.

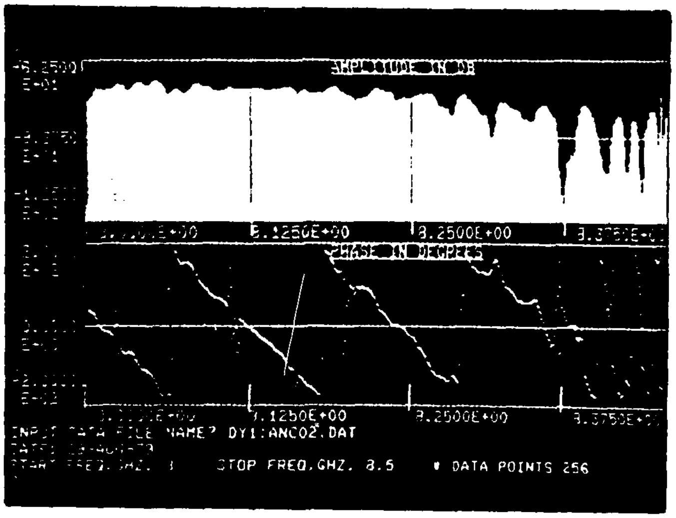


Fig. 2.11 System clutter corrected for transfer function; 8.0-8.5 GHz.

described but also takes into account the antenna system variations as a function of frequency:

$$R1(f)=C2(f)*T(f)+I(f)+R2(f)*T(f) \quad (2.4)$$

Here C2(f) and R2(f) contain the antenna system response multiplying the actual values of corrected reference target and system clutter data.

$$R2(f)=R(f)*A1(f) \quad (2.5)$$

$$C2(f)=C(f)*A1(f) \quad (2.6)$$

This response A1(f) takes into account the varying amount of power received and transmitted as a function of frequency in the antenna system. If the reference target is chosen to have a constant cross section and linear phase over the frequency range of interest then R(f) is of constant amplitude and linear phase. Solving for R2(f):

$$R2(f)=(R1(f)-I(f)-C1(f))/T(f) \quad (2.7)$$

This leaves R2(f) proportional to A1(f) shifted by a linear phase corresponding to the reference target range.

When the actual target is measured; it is corrected for system errors as was the reference target data and this result is divided the corrected reference target data to yield the final target scatter data.

$$S2(f)=(S1(f)-I(f)-C1(f))/T(f) \quad (2.8)$$

$$S(f)=S2(f)/R2(f) \quad (2.9)$$

This technique may be simplified considerably in the laboratory environment given the signal to noise ratio is greater than 10 db for the scattered signals. In this case only multiplicative errors remain and the additive errors

are masked by the high target scatter signal amplitude. Hence:

$$I(f), C1(f) \to 0$$
$$R1(f) = R2(f) * T(f) \tag{2.10}$$

and therefore:

$$S(f) = S1(f)/R1(f) \tag{2.11}$$

Weir and his group have reported that this technique has reduced equivalent range clutter to -45 db below 1 sq. meter.

There remains one source of error in the scattered signal measurement that cannot be removed by calculation. This error comes from multipath scattering from the object. The target scatters power in all directions. Some of this signal may be reflected off the walls or floor of the anechoic chamber. The signals reflected off the walls is over 48 db down from the incident wave amplitude in the 6.0-12.0 GHz range. However if the target is small in cross section; on the order of 100 sq. cm.; then it is possible for the walls (on the order of 100 000 sq. cm.) to contribute a significant component to the received signal.

In order to analyze the effect of the multipath scattering, let the directly received signal be written:

$$S_D(t) = A\cos(\omega t + \Psi) \tag{2.12}$$

and the indirectly received signal:

$$S_i(t) = B\cos(\omega t + \Psi + \theta) \tag{2.13}$$

Then the total received signal is given by:

$$S_T(t) = (A^2 + 2AB\cos\theta + B^2)\cos\left(\omega t + \Psi + \tan^{-1}\left(\frac{-B\sin\theta}{A + B\sin\theta}\right)\right) \tag{2.14}$$

Since theta is a function of the indirect path length differences and frequency, it will lead to a periodic variation in the amplitude of the scattered signal. As an example; if the paths differ in length by 1 meter then the amplitude oscillations will occur every 300 MHz given all other factors remain constant.

A series of programs was written to test these various techniques of error removal. They differ in the only in the error removal technique employed; not in file storage or display formats nor in range calculation and removal to be described. These programs used together:

1)Measure and correct the reference target data with files of transfer function and clutter data generated by SYSRES.

2)Measure and correct the target data and finally take the corrected reference target data and remove the antenna system response from the target data.

3)Alternately for high SNR; calculate the correct scattered target signal directly using the reference target data.

4)Calculate and remove phase shift due to range from the target signal after error correction

These programs are briefly described and differ in the mentioned categories:

SPHERE-Reads transfer function and clutter data files generated by SYSRES; takes the reference or object data and corrects for errors in the

equipment.

SPHER2-Measures clutter and reference target data. It then subtracts clutter and divides the target data by the reference target transfer function.

SPHER3-Measures reference target and object signals ignoring clutter, and divides the object data by the reference target complex field amplitude data.

In order to implement the complete error correction process program SPHERE would be run twice; once for the reference target and then again for the test object. This data would be stored for later retrieval. Program SPHER3 would read these files and process then such that the test object complex field data would be divided by the reference target data. For high SNR cases; program SPHER3 alone would be run: first measuring the reference target and then the test target and finally dividing them yielding the final result. Listings and a more complete description of program operation is given in the program appendix I.

III RANGE PHASE SHIFT ANALYSIS

This chapter contains an analysis of the effects on the phase shift due to target range on coherent imaging of a target. It includes a discussion of some of the available techniques for the removal of this phase shift and the required perfor mance of these systems based on bandwidth and signal to noise ratio.

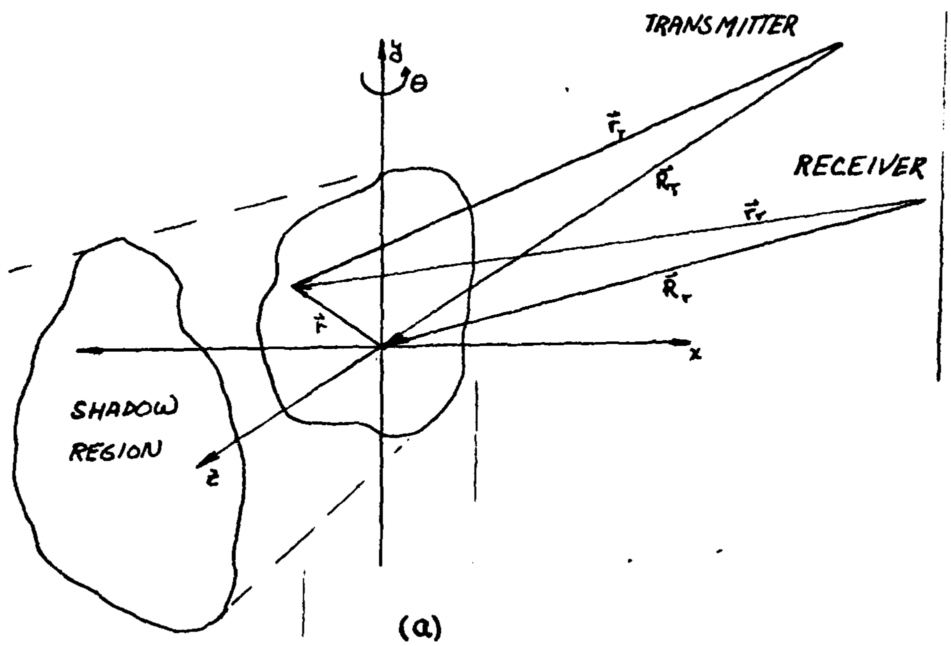
3.1 The effects of range phase on imaging

As previously described by Farhat and Chan ;[4]; the scattered field of the scattering target is given by:

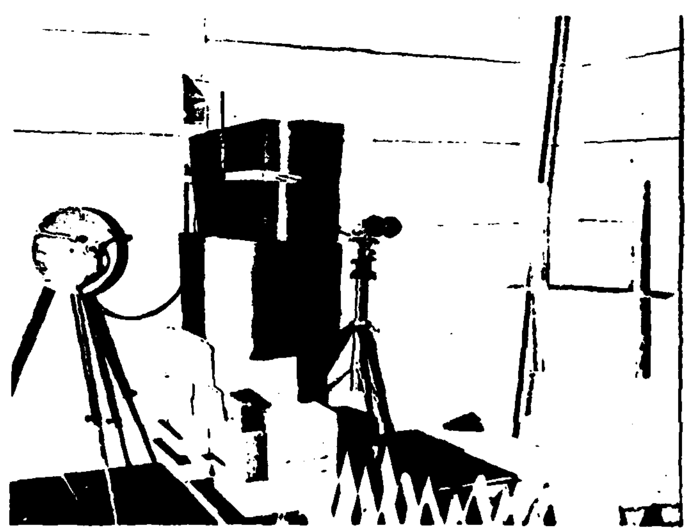
$$\psi(k, R_T, R_r) = \frac{jk}{2\pi(R_T+R_r)} e^{-jk(\vec{R}_T+\vec{R}_r)} \int_{-\infty}^{\infty} \mathcal{U}(\vec{r})\, e^{-jk(\hat{R}_T+\hat{R}_r)\cdot\vec{r}}\, d\vec{r} \qquad (3.1)$$

Where $\vec{R}_T$ and $\vec{R}_r$ are the vectors from the receiving and transmitting antennas to the target respectively and k is the wave vector of the illuminating wave. In this case the integration is over the extent of the object. The integral term is independent of the range of the target. While the term preceeding the integral is target independent and contains range information. The argument of the complex exponential is a linear phase function of frequency.

In the single receiver=transmitter pair arrangement; shown in fig.3.1, the spatial frequency domain ($\vec{p}$ space) data is collected in a plane perpendicular to the axis of rotation. In this case the multiplication of the range phase factor leads to the convolution of the transforms of the the range and target functions in the spatial domain. The real part of the range frequency domain function is a



(a)



(b)

Fig. 2.12 a) Target and antenna placement relative to target considered in analysis. b) Experimental configuration in anechoic chamber; note target on rotating pedestal in forefront.

radially symmetric sinusoidal function:

$$\mathcal{R}\left\{e^{-jk(R_T+R_r)}\right\} = \cos k(R_T+R_r) \tag{3.2}$$

This transforms to a circular ring of radius (R_T + R_r). This indicates that each point of the reconstructed image is convolved with this circular ring pattern; seriously degrading the target image. In fact any error in the removal of phase will distort the image in this manner. The effect of removing the range phase factor is equivalent to the focusing of the system on the target.

There are several other reasons for the removal of the factor:

$$\frac{jk}{2\pi(R_T+R_r)}\, e^{-jk(R_T+R_r)} \tag{3.3}$$

from the received data. If the data is discrete then the considerations of aliasing and sufficient data sampling rate are introduced. When the sampling rate in the frequency domain is (f) then the maximum target range before aliasing will occur is (c/4* f). However if the phase factor is removed and the target is of smaller dimension L than the range, then the sampling rate in the frequency domain need only be sufficient to prevent aliasing over the dimensions of the object :

$$\Delta f \le \frac{c}{4L} \tag{3.4}$$

This allows the entire resolution capability of the system to be placed on the target itself greatly reducing the data

volume.

Another reason for the removal of this phase factor term can be seen in systems involving multiple receiver-transmitter pairs. For each pair $(\vec{R}_t)$ and $(\vec{R}_r)$ is different and in order for the data to be coherent all phase centers must be equal for an image to be formed.

Several methods have been suggested for the removal of the range phase factor. [4] In all cases it is required that the range removal technique be accurate to within $(\lambda/5)$ for there not to be serious image degradation. It is important to investigate the constraints on the ranging system parameters necessary to attain the required accuracy.

From the scaling theorem in Fourier analysis; a signal cannot be both of narrow bandwidth and short duration.[8]

$$a f(at) \longrightarrow F\left(\frac{\omega}{a}\right) \tag{3.5}$$

We define the duration and the bandwidth of the signal in the following manner: [ ]

$$(\Delta t)^2 = \frac{1}{E}\int_{-\infty}^{\infty} t^2 |f(t)|^2 dt \quad (a) \qquad (\Delta\omega)^2 = \frac{1}{2\pi E}\int_{-\infty}^{\infty} \omega^2 |F(\omega)|^2 d\omega \quad (b) \tag{3.6a,b}$$

where:

$$E = \int_{-\infty}^{\infty} |f(t)|^2 dt = \frac{1}{2\pi}\int_{-\infty}^{\infty} |F(\omega)|^2 d\omega \tag{3.6c}$$

is the signal energy. Then if:

$$\lim_{|t|\to\infty} \sqrt{t}\, f(t) = 0 \tag{3.6d}$$

When applyed to signals scattered by a target this may be translated to range uncertainty:

$$\Delta R\, \Delta f \geq \frac{c}{4\pi} \tag{3.7}$$

This represents a limit when the durations of the signal pairs are as previously defined. However it may be possible to improve the range resolution given that the signal to noise ratio is greater than 10 db.

Consider a sinusoid in narrow band gaussian noise:

$$r(t) = A\cos\omega t + n_c(t)\cos\omega t - n_s(t)\sin\omega t \qquad (3.8)$$

$$n(t) = n_c(t)\cos\omega t - n_s(t)\sin\omega t$$

where n(t) is the noise signal and ns(t) and nc(t) are the quadrature components of the noise signal. The amplitude and phase may be expressed as:[9]

$$|r(t)| = \sqrt{(A+n_c(t))^2 + n_s(t)^2} \qquad (3.9a)$$

$$Arg(r(t)) = \tan^{-1}\left\{\frac{n_s(t)}{A+n_c(t)}\right\} \qquad (3.9b)$$

Since the noise is gaussian nc(t) and ns(t) are gaussian. Assuming that the SNR is high the phase may be approximated by:

$$Arg(r(t)) = \tan^{-1}\left\{\frac{n_s(t)}{A}\right\} \simeq \frac{n_s(t)}{A} \qquad (3.10)$$

Also since the noise is white $n_s(t)$ may be related to the bandwidth of the receiving system.

$$\sigma_{n_s}^2 = 2N_oB \qquad (3.11)$$

where ($\sigma_{n_s}^2$) is the variance of the $n_s(t)$ quadrature phase component. The probability density of the phase may be written as:

$$f(\theta) = \frac{A}{\sqrt{2N_o\pi B}}\, e^{-A^2\theta/4N_oB} = N\left(0, \frac{\sigma_{n_s}^2}{A^2}\right) \qquad (3.12)$$

This leads to an interesting result; the variance of the

phase is the inverse of the SNR:

$$\sigma_\phi^2 = \frac{\sigma_{n}^2}{A^2} = \frac{1}{SNR} \tag{3.13}$$

Translating this result to an uncertainty relationship the phase uncertainty may be expressed:

$$\Delta\omega\,\Delta t \geq \sqrt{\frac{8NB}{A}} \tag{3.14}$$

The uncertainty in phase is the product of the time and frequency uncertainties. This leads to an expression for the range resolution as a function of the SNR.

$$\Delta f\,\Delta R \geq \frac{c}{2\pi\sqrt{SNR}} \tag{3.15}$$

Wide band ranging systems measure range by calculating the propagation delay of the signal. In one such system a high speed code is transmitted. The received signal is correlated with the original coded signal in a delay locked loop. The value of the control signal in the loop is proportional to the target range. Obviously the resolution is only as good as the the period of one of the code bits(chips). Other wide band systems use other signals for ranging(chirps,walsh functions) to obtain high range resolution. [10], [11], [12]

The system implemented here at the Graduate Research center of the Moore school is a coherent amplitude-phase measurement facility. Ranging techniques that may be integrated into this system are therefore of special interest. The phase of a point scatterer is a linear function the frequency. This directly corresponds to the

phase factor preceeding the scattering integral in eq ( ). If the target consists of multiple scattering centers; then each of these will be represented as a delta function in the in the reconstructed image. This suggests a technique using Fourier analysis to determine range. First place the reference target in the microwave field and measure the phase/amplitude response over as wide a frequency range as possible. Then inverse transform this one dimensional collection of data. This will transform to essentially a delta function occurring at the time corresponding to the propagation delay. This will occur when the target has a single scattering center such as a sphere. Even when the object is more complex the inverse transform will be centered around the transit time. In this Fourier technique for range determination the resolution (Δx) is inversely related to the frequency sweep width.

$$\Delta x = \frac{c}{2\Delta f} \tag{3.16}$$

The factor of 1/2 results from the fact that the range is half the signal propagation path length.

A factor to be considered is that different scattering centers are visible from different receiver positions. It is imperitive that all when several receivers are used simultaneously that all choose the same scattering center as the phase center for range removal. If the various p[illegible] centers do not coincide , the fringes of the hologram [illegible] be skewed. The data sets from each of the receive[illegible] brought into alignment using an adaptive

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Information is lost in the hologram if the phase centers for the scan lines are separated.

When this process is automated the sweep is done by measuring the response at discrete frequency points. The amplitude and phase are stored at N frequency points in the sweep range. The range at which aliasing will occur is given by:

$$R_{alias} = \frac{c}{4\Delta f} \tag{3.17}$$

This system exhibits processing gain ; a quality of all systems which spread a baseband signal into a wide spectrum. For this system the processing gain is a function of the number of measurements and the sweep width.

$$\begin{aligned} Gain &= \frac{\Delta f}{f_{stepsize}} = n \\ Gain\,db &= 10 \log_{10} n \end{aligned} \tag{3.18}$$

As an example, for 256 measurement points, this would give 24 db of processing gain.

A set of subroutines was written to test this range removal technique. In one of them , RANGE, the range of the strongest scattering center is calculated and in the other ,RANCOR, the phase factor is calculated and removed from the target data. These subroutines are used in programs SPHERE,SPHER2 ,and, SPHER3.

The time domain equivalent of this technique is fitting a linear trend to the phase signal from the network analyzer. Since the phase signal is modulo (2π);this means

estimating the frequency of a ramp waveform; either using a least squares approximation or implementing the equivalent of a phase locked loop. The slope of the ramp waveform is proportional to the range of the target. The accuracy to which the range may be determined depends on the sweep width, the target structure and the noise in the system. If the sweep is wide, then there will be more data with which to estimate the slope. Noise in the data will obviously interfere with the estimation process as will as any phase shifts due to the target structure.

Another type of system for generating a reference signal utilizes a Target Derived Reference. This system has been extensively studied at the Electro-Optics and Microwave Optics laboratory.[13] A brief review of the ideas developed to date in this regard are given below. The complex exponential in the integral term of scattered signal remains constant when the target is small relative to the illuminating signal wavelength.

$$\psi(\vec{p}) = \int_{-\infty}^{+\infty} \mathcal{U}(\vec{r})\, e^{-j\vec{p}\cdot\vec{r}}\, d\vec{r} \simeq e^{-j\vec{p}\cdot\vec{r}} \int_{-\infty}^{\infty} \mathcal{U}(\vec{r})\, d\vec{r} \qquad (3.19)$$

This is true if (L_{obj}) is sufficiently small such that($\vec{p}\cdot\vec{r} \ll 1$). In this case the integral value approaches a constant multiplied by a linear phase; i.e. a point scatterer. It will only occur when the target dimensions are less than a tenth wavelength of the illuminating signal, placing it in the Rayleigh scattering region. The TDR signal is mixed harmonically with a phase locked scattered

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signal at the imaging frequency. here the two signal sources are phase locked by a phase synchronizer. The high frequency sweeper acts as the slave signal source. These two signals simultaneously illuminate the target. Harmonic mixing of the suitably limited TDR and imaging signals will yield the desired phase corrected data.

Another technique which is useful for ranging is the frequency displaced reference method. Here the carrier is displaced (Δf). It is important that the object not contribute to the phase shift; hence the displacement must satisfy the following condition:

$$\Delta f << \frac{2c}{L} \tag{3.20}$$

In this case the target structure will not contribute to the net phase shift. The range to the target phase center is given by:

$$R = \frac{\Delta \phi c}{\Delta f 2\pi} \tag{3.21}$$

c - speed of light

Where ($\Delta\phi$) is the change in phase for the carrier and displace carrier signals respectively. If the frequency shift is small then the phase shift will not be large. The resolution of the system then is directly related to the SNR in the receiver channel since the accuracy to which the phase may be measured is a function of the channel noise. If the displacement is large then the phase shift is increased and the SNR requirements on the signal for a specific resolution is decreased. This relationship may be expressed:

$$R_{Resolution} = \frac{\sigma_{\phi} c}{\Delta f 2\pi} = \frac{\sqrt{2N_0B}\; c}{4\pi A \cdot \Delta f} \tag{3.22}$$

The factor of 2 comes about due to the phase uncertainty existing in both the carrier and displaced carrier signals.

An alternate method for implementation of the displaced frequency ranging system is a swept frequency chirp system. The ranging signal frequency is given by :

$$f(t) = f_0 (1 + \alpha t) \qquad \text{where } \alpha = \frac{f_1 - f_0}{T} \tag{3.23}$$

T- Sweep period

f_0- Initial frequency for sweep

f_1- final frequency

The scattered signal from the target is given by:

$$f_s(t) = f_0 + \frac{d\phi}{dt} - \frac{f_0 \alpha}{c} (R_T + R_r) \tag{3.24}$$

where ($d\phi/d_t$) is the change in frequency due to the target structure. The range of the target may then be simply calculated using a frequency counter and sweep time T and sweep width ($f_1 - f_0$). This method could be used in an analog imaging system.

Other Target Derived Reference systems simulate the low frequency reference carrier by measuring the change in phase of the imaging frequency over a narrow band. Over this small band the phase shift is assumed to be linear. In one system a series measurements is made for each frequency point. The first displaced down by a small amount, (Δf); the second at f; and the final measurement at ($f+\Delta f$). Phase and amplitude are measured at each frequency and processed to obtain the target range. In a similar system the three

signals are transmitted simultaneously by amplitude modulation of the carrier. These systems are presently under intense investigation by other workers at the Electro-Optics and Microwave Optics Laboratory of the Moore School.

3.2 Practical considerations for range phase removal

Several factors influence which of these systems would be of value in a long range imaging radar system versus a controlled laboratory environment. The distribution of the reference signal for complex field amplitude measurement makes implementation of system requiring a central reference difficult to implement. Techniques are being considered in the E.O. laboaraty for reference distribution using fiber optic that might remove this limitation. Reference distribution is accomplished in the lab readily since the distances are small.

Typical transmitter-receiver pattern arrangements might be the Wells array [14], an orthagonal pattern of receivers and transmitters, a circular array of receivers with central transmitter or a random array. Each combination of receiver and transmitter contributes another line in the frequency domain 3D data volume. For this reason it is advantageous that all combinations of the receivers and transmitters are utilized for data collection. Reference signal distribution difficulty therefore leaves the TDR systems as the only practical alternatives for long range imaging systems. The AM TDR system eliminates

reference distribution by transmitting the reference signal along with the imaging signal and automatically corrects for the target range. TDR systems have the additional advantage that they have immunity to turbulence and inhomogeneities in the propagation medium since both the reference and imaging signals follow the same path.

There are several considerations for determining the best TDR system. Narrow band systems yield only a weighted average of the range to the phase center of the object while wide band system can resolve individual scatters on the target body. A wide band system could adaptively choose one of the scattering centers for the phase reference of the system. A narrow band system could not do this, and any error would introduce image distortion. The narrow band systems have the advantage of automatically correcting the target data for the range phase factor.

For the laboratory imaging experiments a TDR system would not yield the correct phase factor since in this arrangement the object rotates about an axis and the correct phase factor would be a constant, representing the phase shift to the axis of rotation ,not the target. The TDR system looks only at the range to the strongest specular reflector on the target surface.

If movement of the target is utilized for aperture synthesis then only one receiver-transmitter pair is required for 3-D imaging and the adaptive system is not required.

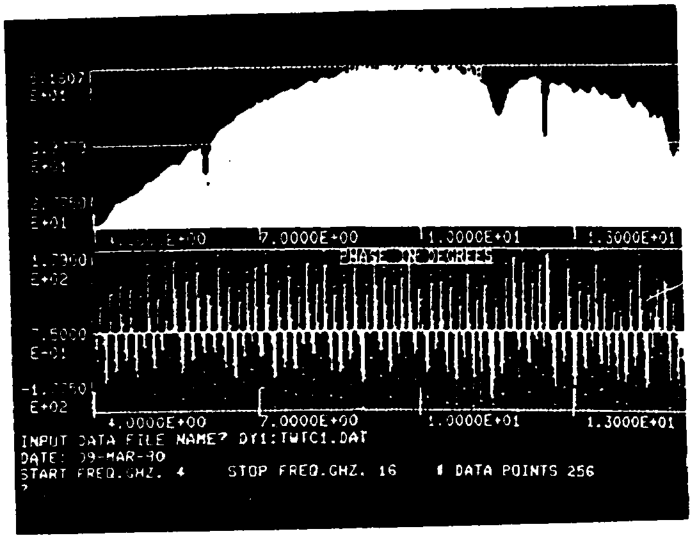
Knowledge of the placement of the data in the 3-D frequency domain volume is necessary for the reconstruction of the hologram. The azimuth and elevation angle of the target can be obtained from a conventional radar located at a central location where the data processing and reconstruction is taking place.

IV SYSTEM IMPLEMETATION OF SWEPT FREQUENCY IMAGING

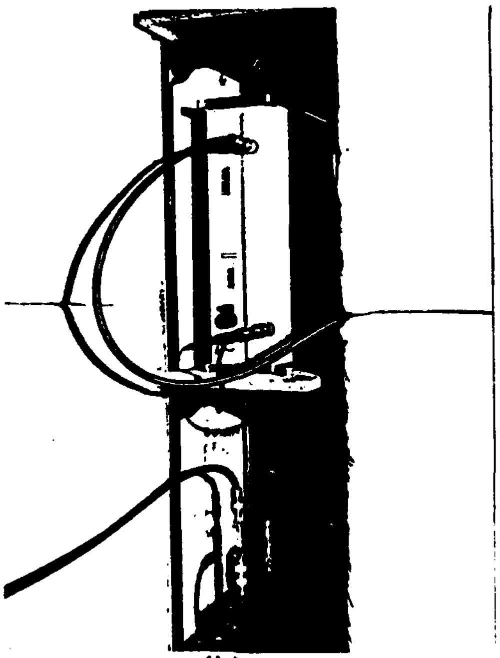
This section of the thesis will describe the research that was done in order to obtain a clear understanding of system performance. Following this will be a section of the thesis devoted to the experimental verification of the swept frequency imaging theory.[ ] The theory is applied in the simulation of the experiments performed.

4.1 System repeatability

An important parameter of system performance is the repeatability of an experimental measurement. The frequency range over which this possible for the equipment used indicates the bandwidth for which imaging is possible. There are several feedback loops in the system which allow it to track variations in the transmitted signal level. The traveling wave tube amplifier characteristic is shown in fig.4.1. This plot is on a logarithmic scale, indicating that the TWT amplifier gain drops off exponentially below 7.0 GHz and above 15.0 GHz. This measurement was done by first measuring the system response(cables, connectors,attenuator) less the TWT amplifier and then subtracting this response from the TWT amplifier plus system data. A sample of the amplifier output is sampled using a 20 db directional coupler and this is fed to the RF input of the HP 8743A reflection-transmission (R-T) unit. A crystal detector at the 'unknown' port of the R-T unit rectifies a portion of this signal. The detector output is brought to the external signal leveling input of the HP 8620C sweeper.



(a)



(b)

Fig. 4.1 a) Traveling Wave Tube amplifier gain characteristic in db; 4.0-16.0 GHz. b) Varian VA 618G TWT amplifier (bottom) and HP 8743A reflection-transmission unit (top).

The leveling circuit of the sweeper can level the output over a 20 db range. In addition the AGC in the HP 8410B network analyzer can track the reference signal amplitude over a 40 db dynamic range. System performance may be seen in fig.4.2 for a cylindrical target 7 meters distant from the receiving and transmitting antennas. Two consecutive measurements of the target were made and the results divided. The ideal response would be 0 db flat amplitude and 0 degree phase difference over the entire frequency sweep. With few exceptions due to phase noise at the (+/-) transition point, the system has the desired repeatability in the 5.5 to 16.0 GHz range. Below 4.5 GHZ there are phase errors due to insufficient reference power whereas above 15 GHz errors come about due to the low amplitude of the received signal. Noise may be cancelled by taking multiple measurements and finding the mean. These results indicate the useful data can be recorded in the 5.5-16.0 GHz range

4.2 Computer control of target rotation

When implementing a frequency diversity system with just one pair of receiving and transmitting antennas, the target must then be rotated in the electromagnetic field and the scattering measured for different rotation angles. The target used in the experimental system rotates on a stepper motor driven pedestal. The column of the pedestal is 1 1/2 meters in length and is made of styrofoam material with minimal cross section. A stepper motor controls table rotation precisely. In order for the pedestal to rotate one

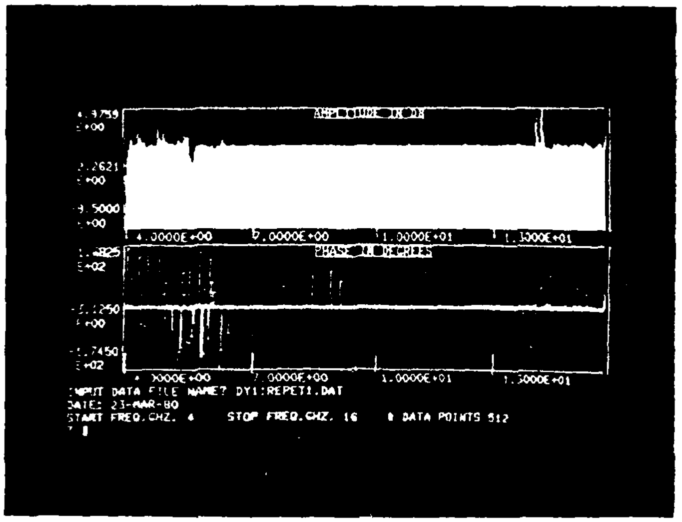


Fig. 4.2 System repeatability for two consecutive scattering measurements of a 80 cm long cylinder 7 cm in diameter; 4.0-16.0 GHz.

revolution the motor must be stepped 10 000 times. The motor is under direct computer control using the digital output port the MINC. A FORTRAN subroutine STEP2 was written for control of the stepper motor. It calculates the number of steps required for a specified angular rotation and moves the table clockwise or counter clockwise based on the direction parameters passed in the subroutine call. The stepper and pedestal are shown in fig.4.3.

4.3 Sphere Simulation

For the calibration of a radar system a reference target is required. The most commonly used reference target is the conducting sphere since its high degree of symmetry does not favor any particular polarization for the incident illumination. Both the bistatic and monostatic scattering of a metallic sphere was simulated.

The general solution for the plane wave electro-magnetic scattering of the sphere was first done by Mie in 1908.[15],[16] In the far field approximation, the scattered field is given by:

$$E_s(k_0 r,\theta,\phi) = E\frac{e^{ik_0 r}}{k_0 r}\left[\cos\phi\, S_1(\theta)\,\hat{\theta} - \sin\phi\, S_2(\theta)\,\hat{\phi}\right] \tag{4.1}$$

where

$$S_1(\theta) = \sum_{n=1}^{\infty}(-1)^{n+1}\left[A_n\frac{P_n^1(\cos\theta)}{\sin\theta} + iB_n\frac{d}{d\theta}\left\{P_n^1(\cos\theta)\right\}\right] \tag{4.2}$$

and

$$S_2(\theta) = \sum_{n=1}^{\infty}(-1)^{n+1}\left[A_n\frac{d}{d\theta}\left\{\frac{P_n^1(\cos\theta)}{\sin\theta}\right\} + iB_n\frac{P_n^1(\cos\theta)}{\sin\theta}\right]$$

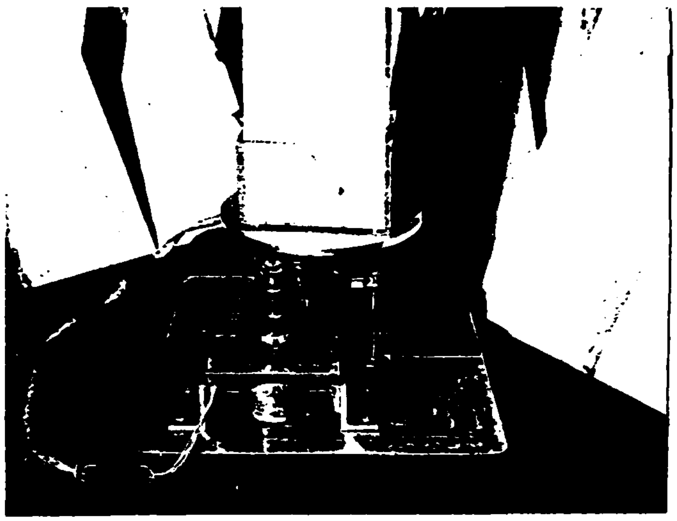


Fig. 4.3 Stepper motor and rotating pedestal.

$S_1(\theta)$ and $S_2(\theta)$ are called the complex far field amplitudes for the $(\hat{\theta})$ and $(\hat{\phi})$ polarizations respectively. The quantity in the square brackets of eq. 4.1 is called the scattering function.

$$F(\theta,\phi) = \cos\phi\, S_1(\theta)\,\hat{\theta} - \sin\phi\, S_2(\theta)\,\hat{\phi} \tag{4.4}$$

The scattering cross section in any arbitrary polariztion $(\hat{\eta})$ for an incident wave polarized in the $(\hat{\tau})$ direction may be written:

$$\sigma_n(\theta,\phi) = \frac{4\pi}{k^2}\left|F(\theta,\phi)\right|^2\left|\hat{\tau}\cdot\hat{\eta}\right|^2 \tag{4.5}$$

Where $(\hat{\eta})$ is the polariztion of the incident wave and $(\hat{\tau})$ is the polariztion vector of the receiving system. For the perfectly conducting sphere the coefficients A_n and B_n are:

$$A_n = -(-i)^n \frac{2n+1}{n(n+1)} \frac{j_n(k_0a)}{h_n'(k_0a)} \tag{4.6a}$$

$$B_n = (-i)^n \frac{2n+1}{n(n+1)} \frac{[k_0a\, j_n(k_0a)]'}{[k_0a\, h_n'(k_0a)]'} \tag{4.6b}$$

$j_n(k_0a)$ - Spherical Bessel function

$h_n'(k_0a)$ - Spherical Hankel function

$P_n^1(x)$ - Associated Legendre function

k_0 - Wave number of incident wave

a - Sphere radius

The prime on the expression for B_n denotes differentiation with respect to (k_0a).

Polynomial approximations exist for the Mie series exact solution.[15] Different polynomials are used for the three frequency regions for scattering. These are: low

frequency or Rayleigh region $(k_0 a)<.4$; the resonance region $.4<(k_0 a)<20$; and finally the high frequency or physical optics region $(k_0 a)>20$. Two programs BISCAT and SPSCAT implement both bistatic and monostatic cases in the three frequency regions. Fig.4.4 shows the monostatic scattering of the sphere as calculated. This is exactly the same answer for the scattering of the sphere as the exact solution. The horizontal axis is in terms of the dimensionless quantity $(k_0 a)$. Figure 4.5 a,b,c and d show the bistatic scattering of the metallic sphere of bistatic angles of $30^\circ, 60^\circ, 90^\circ$, and 120° degrees. Note that the approximation are only valid in the range:

$$\delta < \theta' < \pi - \delta \qquad (4.7)$$

where

$$\delta = O\left(\frac{1}{k_0 a}\right)$$

which leads to the discontinuities for small (k a) at large bistatic angles. BASIC programs BIDISP and SDISP generate the graphs for the sphere simulations. These programs are in appendix II.

An important result from these simulations is that at high frequencies the scattered signal is of constant amplitude and linear phase irrespective of the bistatic scattering angle. The only exception to this is the forward scattering case when (θ) equals (π), where the cross section grows without bound as k increases. This indicates that the only portion of the sphere that is scattering for large $(k_0 a)$ is the front face closest to both the receiver and transmitter; and therefore a ray optics approximation

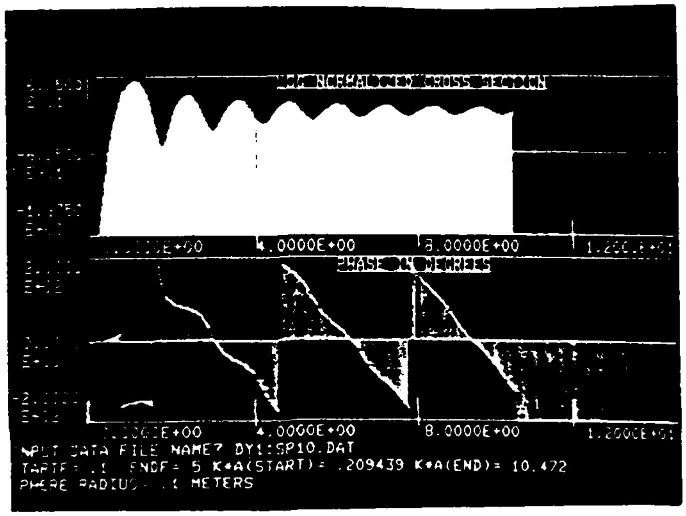
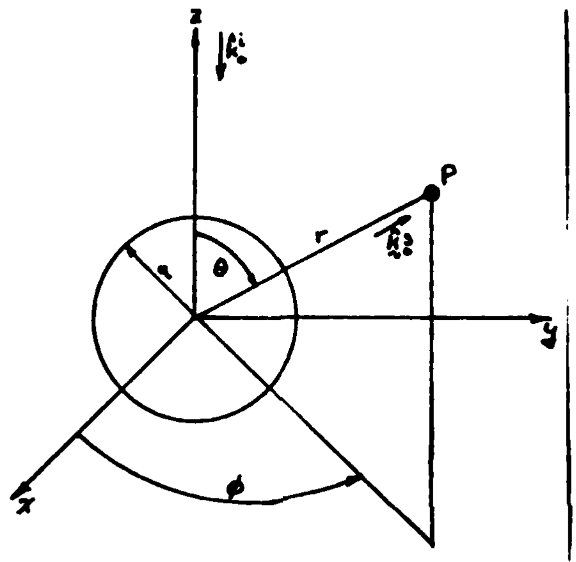
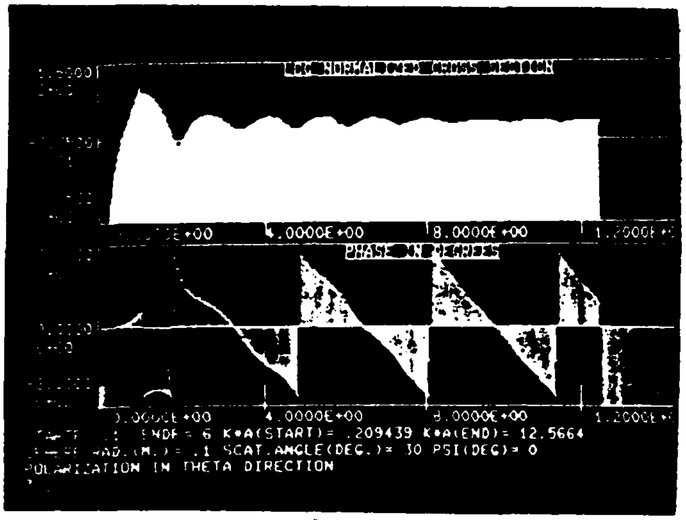


Fig. 4.4 Monostatic scattering for the perfectly conducting sphere. (k a) varies from .2 to 10.5 which corresponds to the scattering of a 20 cm. diameter sphere in the frequency range of .1 to 5.0 GHz. Log normalized cross section: log( ).



(a)

Fig. 4.5 Bistatic scattering of a 20 cm. diameter conducting sphere in the frequency range .1 to 6.0 GHz; $.2<(k_o a)<12.6$; polarization of the receiver equal to scattered wave polarization. a) Geometry for scattering expression. b) Bistatic angle 30°. c) Bistatic angle 60°. d) Bistatic angle 89°. e) Bistatic angle 120°.



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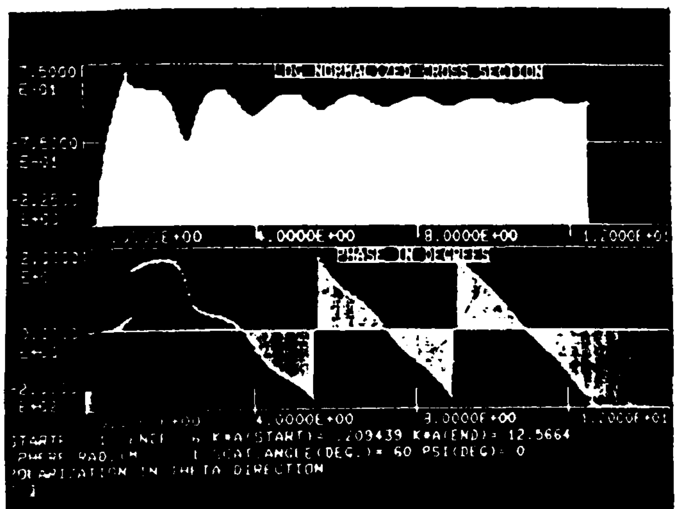
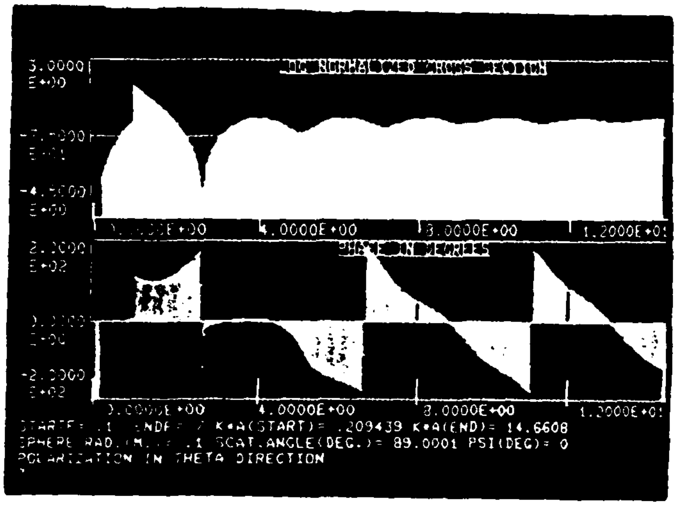
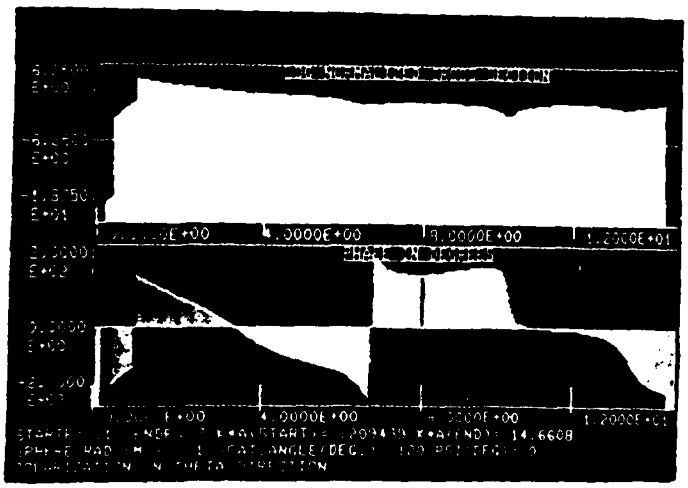


(c)

Fig. 4.5 (contd.) Bistatic scattering of a 20 cm. diameter conducting sphere in the freequency range .1 to 6.0 GHz; $.2<(k_o a)<12.6$; polarization of the receiver equal to the scattered wave polariztion. a) Geometry for scattering expression. b) Bistatic angle 30°. c) Bistatic angle 60°. d) Bistatic angle 89°. e) Bistatic angle 120°.



(d)



(e)

Fig. 4.5 (contd.) Bistatic scattering of a 20 cm. diameter conducting sphere in the freequency range .1 to 6.0 GHz; $.2<(k_o a)<12.6$; polarization of the receiver equal to the scattered wave polariztion. a) Geometry for scattering expression. b) Bistatic angle 30°. c) Bistatic angle 60°. d) Bistatic angle 89°. e) Bistatic angle 120°.

may be applied to find the scattered field.

$$S_1(\theta) = S_2(\theta) = -\tfrac{1}{2} k_o a (e^{-i2k_o a \cos \phi/2}) \tag{4.8}$$

for the bistatic case. In the monostatic case this reduces to:

$$F(0) = -\tfrac{1}{2} k_o a\, e^{-i2k_o a} \tag{4.9}$$

For targets with features larger than a few wavelengths in size resonance effects become minimal.

Another possible reference target is the long cylinder (l >> a). The scattering of the cylinder in the high frequency region when it is oriented vertically yields an answer similar to that of the sphere. For (k a)>5 where a is the cylinder radius, resonance effects disappear and the copolarized scattered field is given by: [15]

$$E_s = E_i \left(\sqrt{\frac{a\cos\phi/2}{2r}}\right) \exp\left\{i k_o 2a \cos \phi/2\right\} \tag{4.10}$$

$$r = (R_T + R_r)$$

The equation for the scattering of the cylinder is used for the computer simulations of frequency swept holography.

4.4 Simulation of frequency swept imaging

A series of frequency swept hologram simulations were done of targets that would later be imaged experimentally. The basic arrangement consists of separate receiving and transmitting antennas which measure the scattering of a target that rotates about an axis. The center of rotation is chosen as the phase center of the imaging system. For this configuration the frequency domain data lies in a plane

perpendicular to the axis of rotation. Therefore the transforms of the holograms will be slices in this plane. The first object hologram simulated was comprised of two cylinders equidistant from the rotational axis. This target is shown in fig.4.6. Approximations for the various distances were derived:

$$r_1 \simeq r - \frac{l}{2} \sin(\phi/2 - \theta) \quad (4.11a) \qquad r_2 \simeq r + \frac{l}{2} \sin(\frac{\phi}{2} - \theta) \quad (4.11b)$$

$$x_1 \simeq r + \frac{l}{2} \sin(\frac{\phi}{2} + \theta) \quad (4.11c) \qquad x_2 \simeq r - \frac{l}{2} \sin(\frac{\phi}{2} + \theta) \quad (4.11d)$$

the waves striking cylinders C1 and C2 are given by:

$$E_{c1} = E_o e^{-ik_o(\vec{x}_1)} \qquad (4.12a)$$

$$E_{c2} = E_o e^{-ik_o(\vec{x}_2)} \qquad (4.12b)$$

The scattered waves from the two cylinders including the cylinder response then follows:

$$E_{sc_1} = E_{c1} \sqrt{\frac{a \cos\phi/2}{2(R_r)}} \; e^{-ik_o(r_1 - 2a\cos\frac{\phi}{2})} \qquad (4.13a)$$

$$E_{sc_2} = E_{c2} \sqrt{\frac{a \cos\phi/2}{2(R_r)}} \; e^{-ik_o(r_2 - 2a\cos\phi/2)} \qquad (4.13b)$$

This is further simplified by combining terms :

$$E_s = 2 E_o e^{ik_o(2a\cos\phi/2)} \sqrt{\frac{a \cos\phi/2}{2(R_r)}} \left\{ \cos k_o l \cos\frac{\phi}{2} \sin\theta \right\} \qquad (4.14\ b)$$

Finally take the real part of this function for display:

$$R(E_s) = C \cdot \cos(2k_o a \cos\frac{\phi}{2}) \cos(k_o l \cos\frac{\phi}{2} \sin\theta) \qquad (4.14b)$$

This was done for a two cylinder target with cylinders 5 cm.

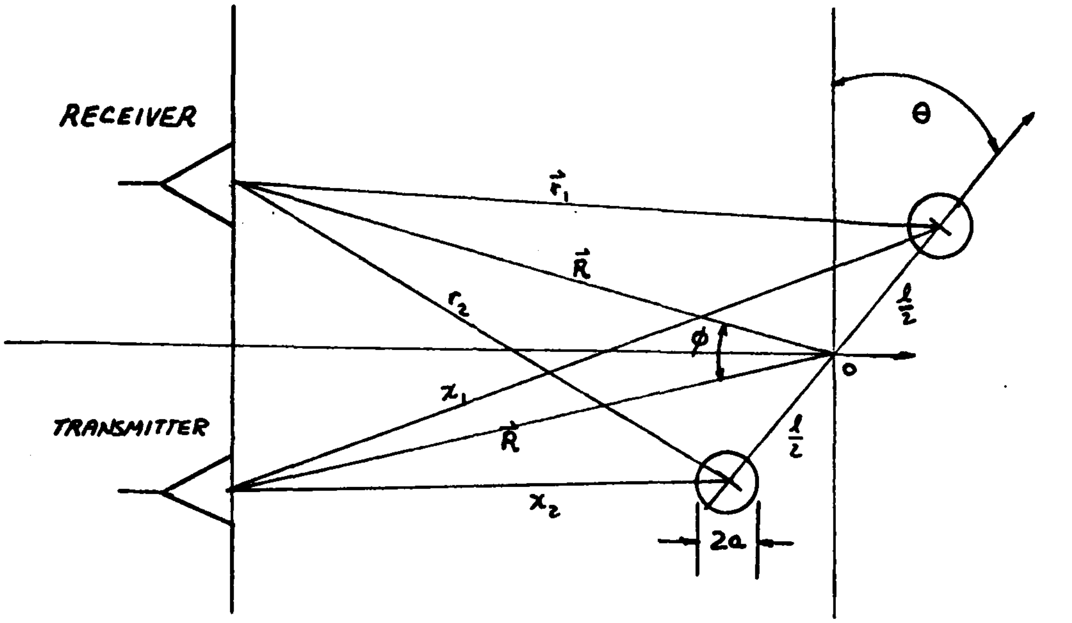
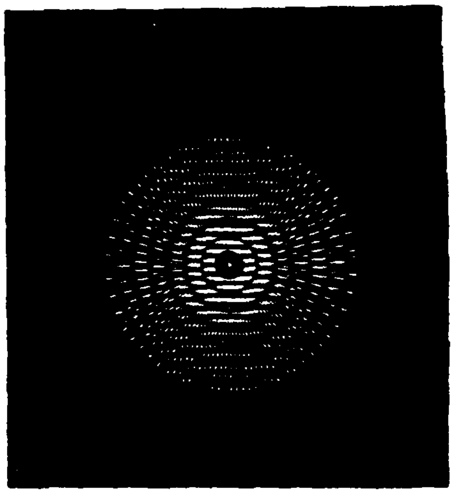


Fig. 4.6 Bistatic scattering of two cylinder target.

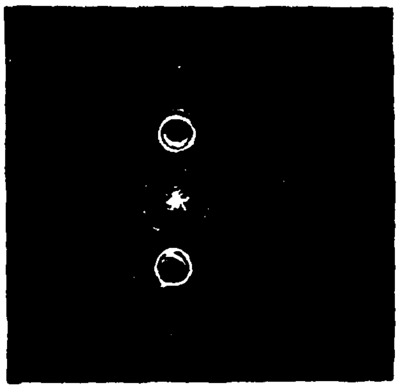
in radius ,separated by 25 cm. using program CYLIN. The results were displayed by program CDISP on a Tektronix 606A CRT display. CDISP gives the option of varying the gray scale compression of the hologram either logarithmically or by constant multiplication. These programs are listed in appendix II. The resultant hologram and the reconstructions obtained through Fourier transformation on the optical bench appear in figs.4.7 a,b The hologram simulated a sweep from 2.0 to 18.0 GHz in 64 frequency steps. The target in the simulation rotated 360 degrees in 128 steps.

Another target simulated which did not have the symmetry of the first target was comprised of two cylinders both mounted to one side of the rotational axis, as shown in fig.4.8. Two simulations were done of this target with varying diameter cylinders. In the first case 7 cm radius cylinders were used. The hologram for this case and the Fourier transform reconstructions are shown in figs.4.8 b,c,d. For the second simulation the target was two cylinders 3.5 cm in radius. In both cases the cylinders were located 10 cm from the center of rotation and the simulation was for a 2.0 to 18.0 GHz sweep. The hologram and the transformed images are shown in figs.4.9 a,b,c. The two cylinder off axis target was simulated by first calculating the copolarized scattered field for a single cylinder:

$$\vec{E}_s = 2\vec{E}_o e^{ikza} e^{-ikl\sin\theta} \qquad (4.15)$$



(a)



(b)

Fig. 4.7 a) Simulation Hologram of two cylinder target; 10 cm. diameter, 25 cm. apart. Frequency range: 2.0-18.0 GHz; 128 lines, 64 points/line. b) Optical Fourier transform of hologram.

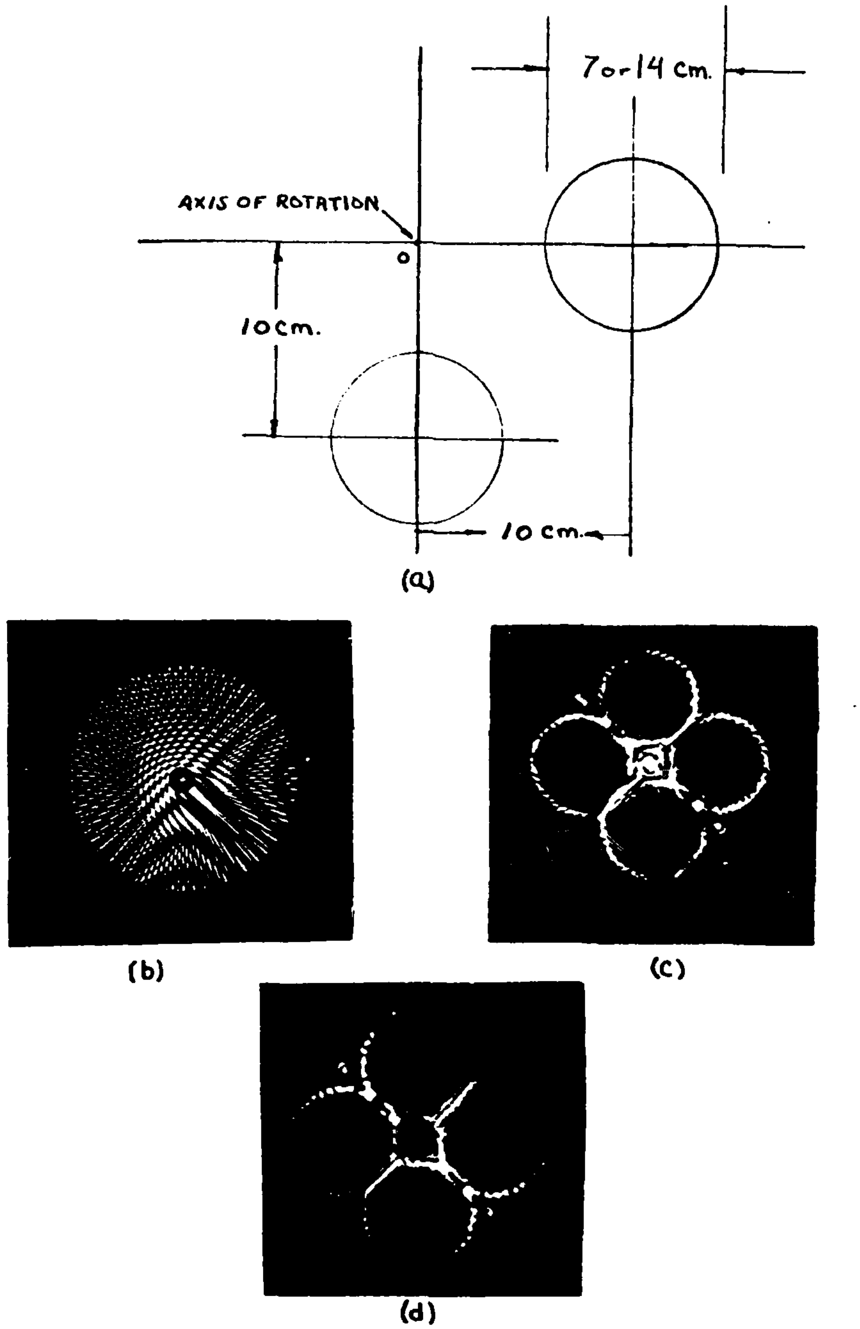


Fig. 4.8 a) Geometry of two cylinder off-axis target. b) Hologram simulation two cylinder off-axis target; 2.0-18.0 GHz; 64 points/line; 128 lines. b) Transform with zero order term. c) Transform with zero order removed.

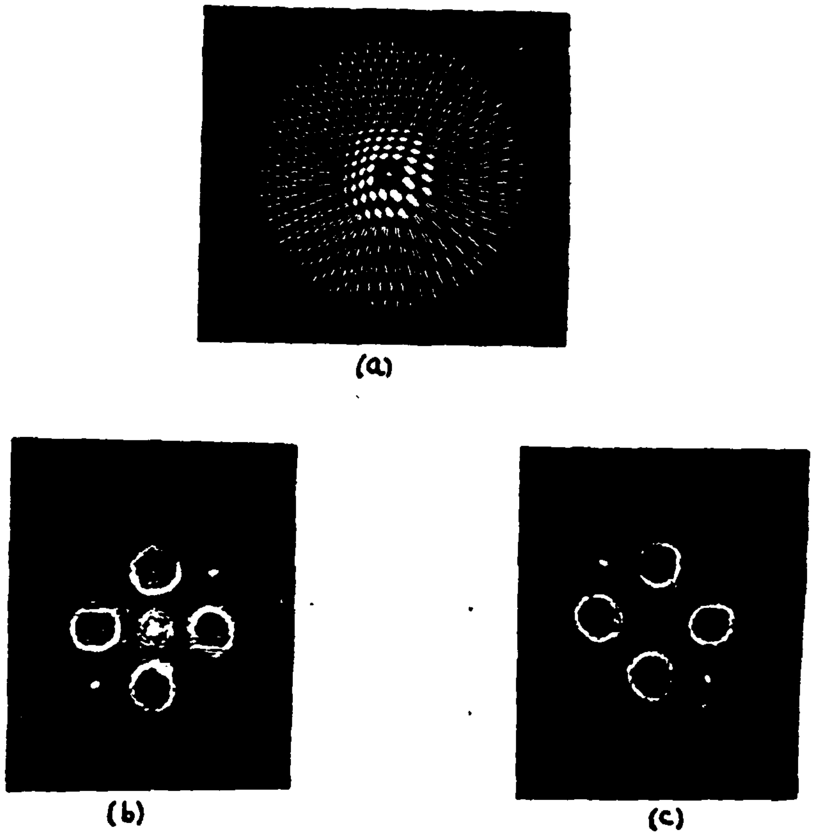


Fig. 4.9 a) Hologram simulation of off-axis two cylinder target with cylinders 7 cm. in diameter; 2.0-18.0 GHz b) Optical Fourier transform with zero order. c) Transform with zero order term removed.

taking the real part:

$$R\{E_s\} = 2E_0\left\{\cos k_0 2a \cos k_0 l \sin\theta + \sin 2a k_0 \sin k_0 l \sin\theta\right\} \quad (4.15a)$$

$$= 2E_0 \cos(k_0 2a - k_0 l \sin\theta)$$

For the two cylinder off axis target, one cylinder is at $(\theta)=0°$ and the other at $(\theta)=90°$, therefore the scattered field is given by:

$$R\{E_s\} = C \cdot \left\{\cos(k_0 2a - k_0 l \sin\theta) + \cos(k_0 2a - k_0 l \cos\theta)\right\} \quad (4.16)$$

In general for an arbitrary set of circular scatterers of radius a and distance l from the origin; the scattered field may be written:

$$R\{E_s\} = \sum_n \cos\left\{k 2 a_n - k l_n \sin(\theta + \theta_n)\right\} \quad (4.17)$$

This gives the capability to simulate the scattering of any target given that it can be decomposed into N spherical scattering centers.

4.6 Experimental results

An experimental system for the implementation of swept frequency imaging was setup in the anechoic chamber at the Graduate Research Center in the Moore School. The frequency range for these experiments was from 6.3 to 16.0 GHz in 64 discrete steps. The targets were rotated 360 degrees in 128 steps. These holograms were then identical in form to the simulations previously done.

The system for error correction and range phase shift removal was that used for high signal to noise ratio signals. The reference target was a cylinder positioned so

that its front face was located on the axis of rotation as in fig.4.10. A plot of system response is shown in fig.4.11. This data represents the combined characteristics of the antennas, amplifier , cables and clutter. In addition it contains the linear phase shift that is the range phase factor. As an example for the two cylinder target shown in 4.12 the raw data, magnitude and phase is shown in fig.4.13. Figure 4.14 shows how this data has been corrected for range phase and system response. This data was generated using the Fortran program SPHER3.

The experimental properties of the two cylinder target were studied extensively. Both the scattering as a function of frequency for a specific orientation of the target and the scattering as a function of angular rotation at specific frequencies was obtained. In figs. 4.15 a,b,c are shown the corrected frequency response of the targe for orientations of 45°,90° and 135° degrees.

Another computer program ANTPAT was written to obtain the radiation pattern of an arbitrary target or antenna. In the two cylinder case the pattern was measured at 5.0,10.0 and 15.0 GHz. Note that when the cylinders are collinear all that is seen is the front surface specular reflection of the one cylinder hence the pattern of a point scatterer in the vicinity of 0° degrees. These patterns are shown in figs.4.16 a,b,c. At high frequencies the lobe spacing is much closer than at low frequencies, consistent with the theoretical result for the pattern. To see this examine the

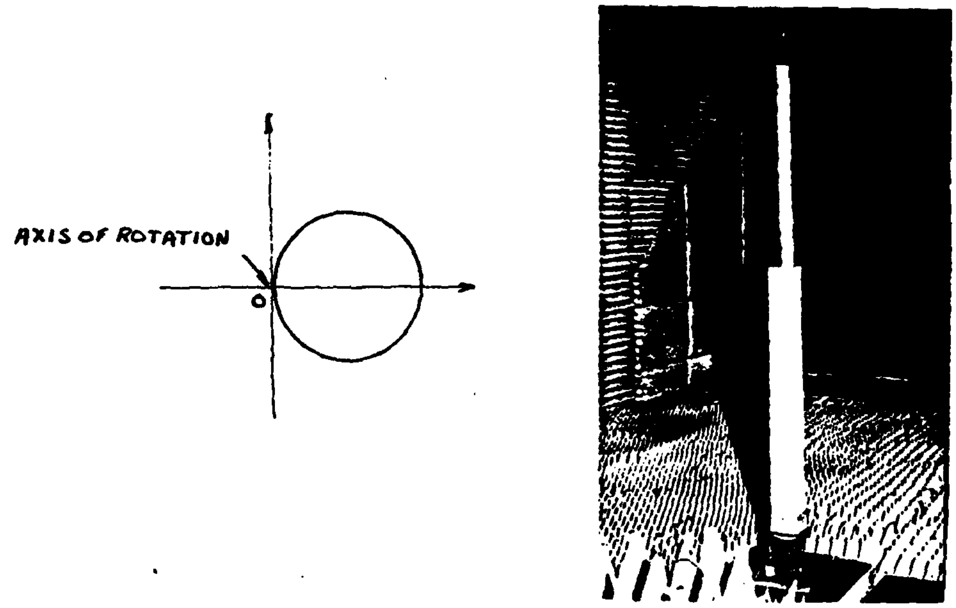


Fig. 4.10 Reference target on pedestal; 80 cm. long cylinder, 7 cm. in diameter.

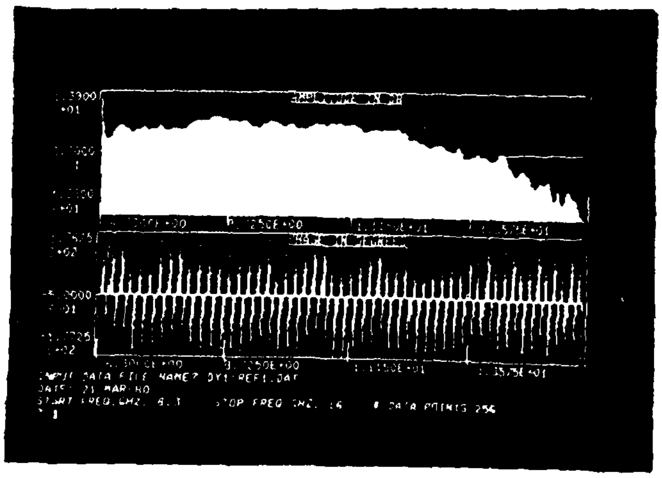


Fig. 4.11 Reference target response including system response and range phase shift; 6.3-16.0 GHz.

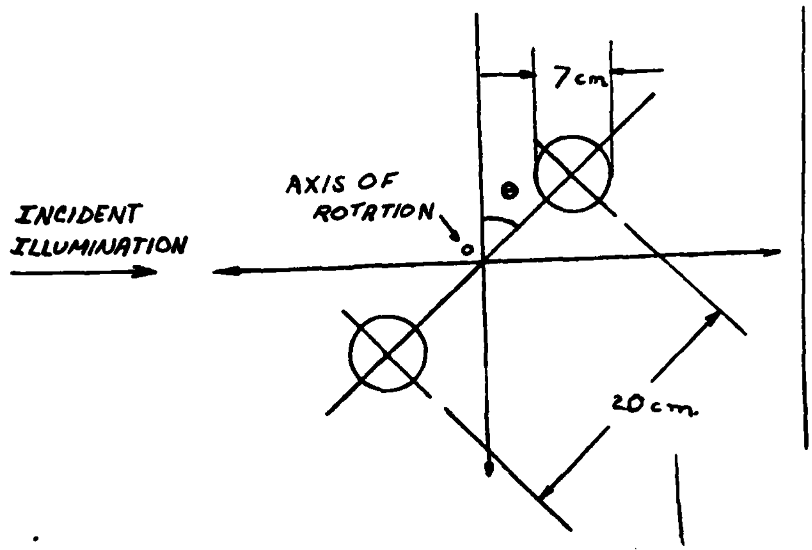


Fig. 4.12 Two cylinder target geometry.

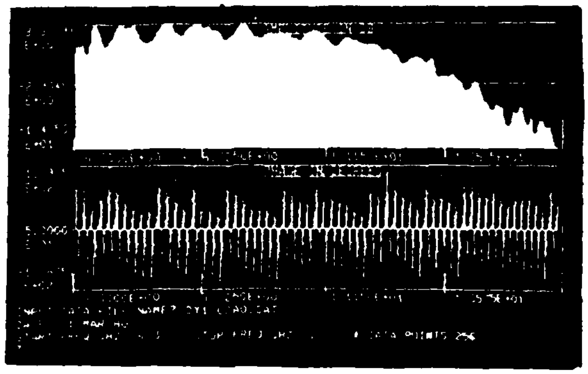


Fig. 4.13 Uncorrected scatter data for symmetrical two cylinder target ; $(\theta) = 0^{\circ}$, 6.3-16.0 GHz.

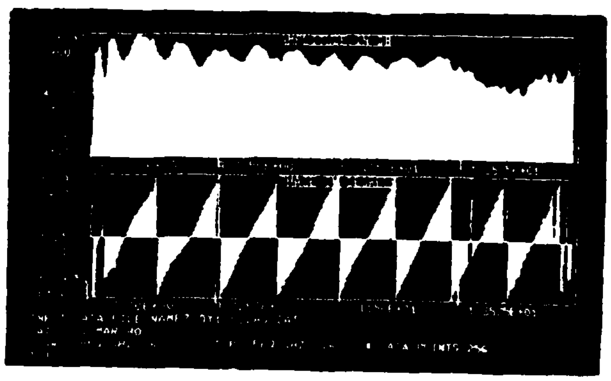
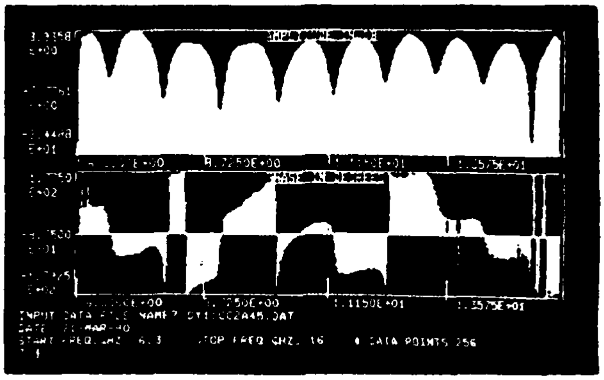
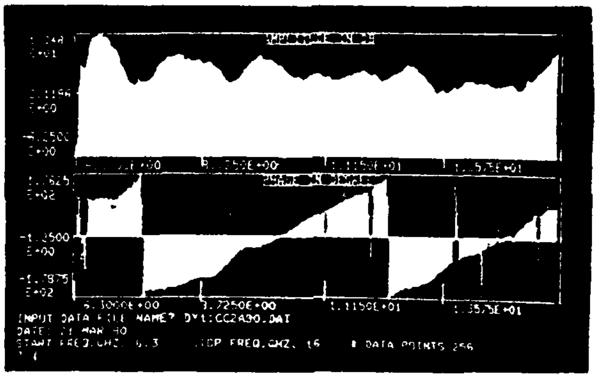


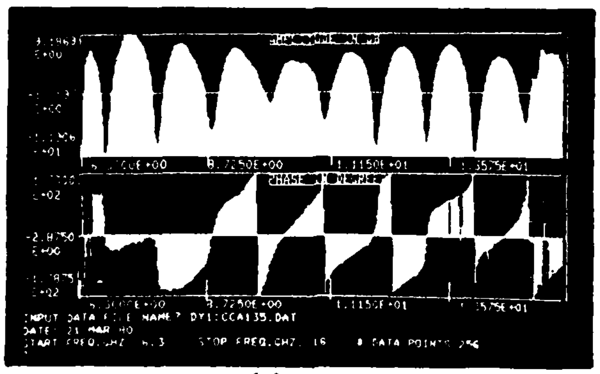
Fig. 4.14 Corrected two cylinder target data using system response of Fig. 4.11.



(a)

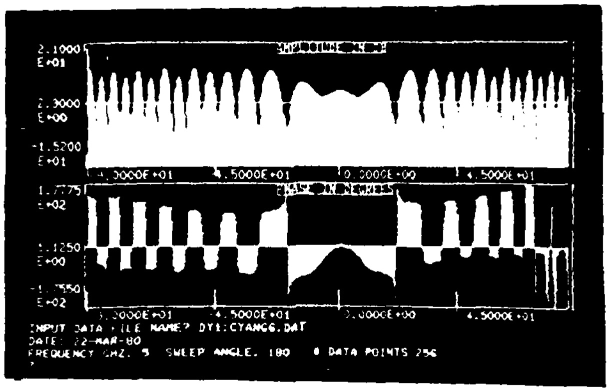


(b)

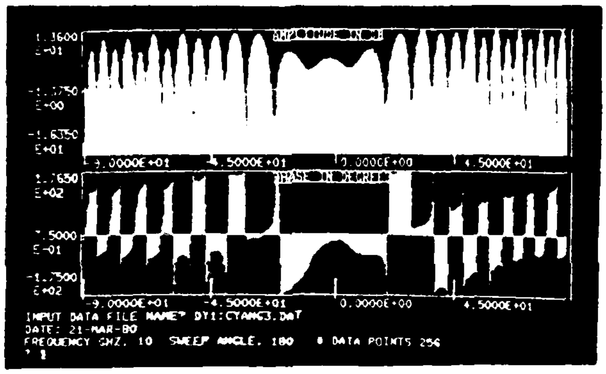


(c)

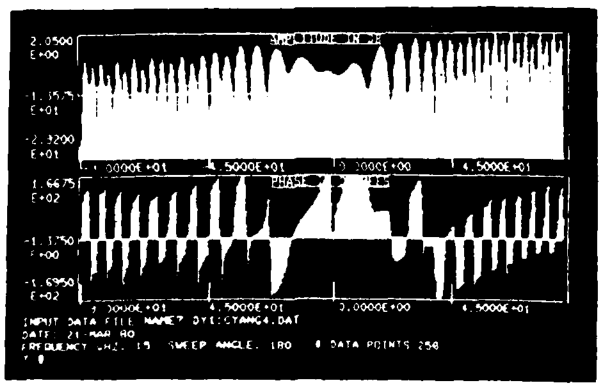
Fig. 4.15 a) Corrected two cylinder symmetrical target response; 6.3-16.0 GHz, (θ)= 45°. b) (θ)=90° . c) (θ)= 135°.



(a)



(b)



(c)

Fig. 4.16 Scattering pattern of two cylinder target of Fig. 4.12 at different frequencies as a function target rotation angle. a) 5.0 GHz. b) 10.0 GHz. c) 15.0 GHZ.

expression for the monostatic scattering of the symmetrical two cylinder target:

$$E_s = C \cdot \{ e^{ik_o 2a} \cdot \cos k_o l \cdot \sin \theta \} \qquad (4.18)$$

The expression for the scattering of the target at a given frequency as a function of angular rotation may be written:

$$E_{S(k_o = k_1)} = C \cdot \cos k_1 l \sin \theta \qquad C\text{-constant} \qquad (4.19)$$

As for the swept frequency response; l sin(θ) remains constant and the hence the swept frequency response is sinusoidal with period dependent on (k_1) and l.

The final test for the system was the generation of actual holograms. The first target measured was the two cylinder target shown in fig.4.17a. The cylinders are of aluminum, 80 cm. in length and 7 cm. in diameter. The real part of the corrected swept frequency data in the range 6.3 to 16.0 GHz was stored and displayed on the CRT. The targets were rotated 360 degrees in 128 steps yielding a total of 8192 points in the hologram (64 points/line * 128 lines). The center of the hologram is at 0 HZ with radial distance directly proportional to frequency. An example is shown in fig.4.17b and the reconstructions in figs.4.17c and d. These Fourier transforms where done optically . [17]

This procedure was followed for other targets not having the symmetry of the first object used. The target type was the same as the simulations done previously. The

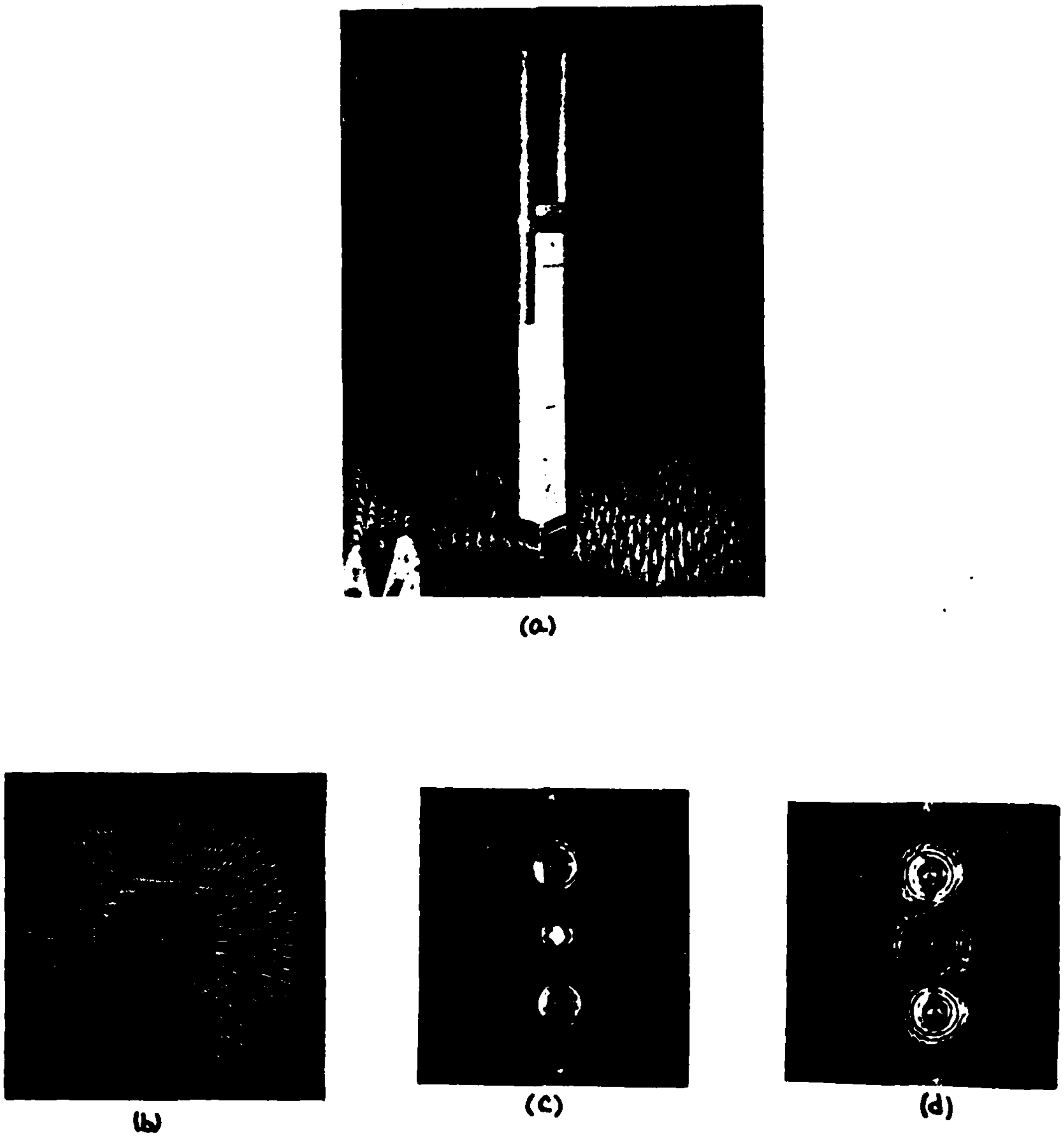
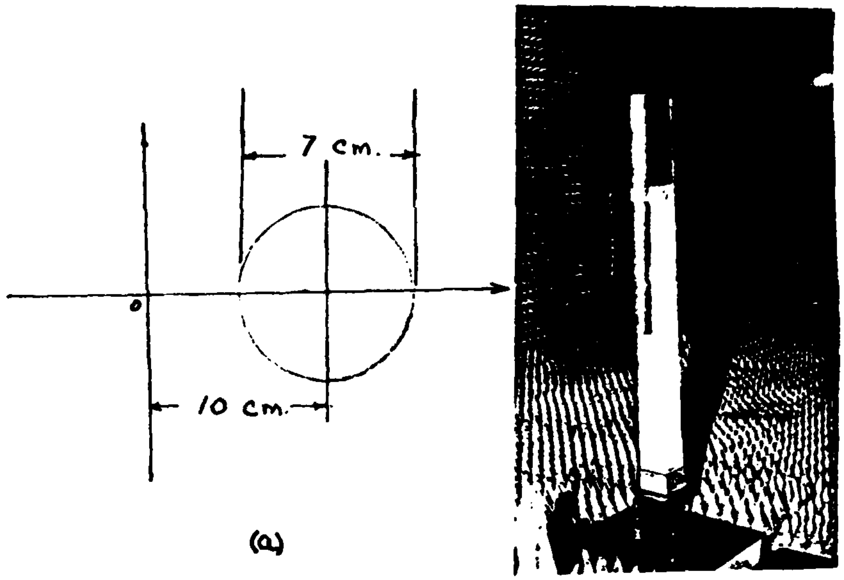
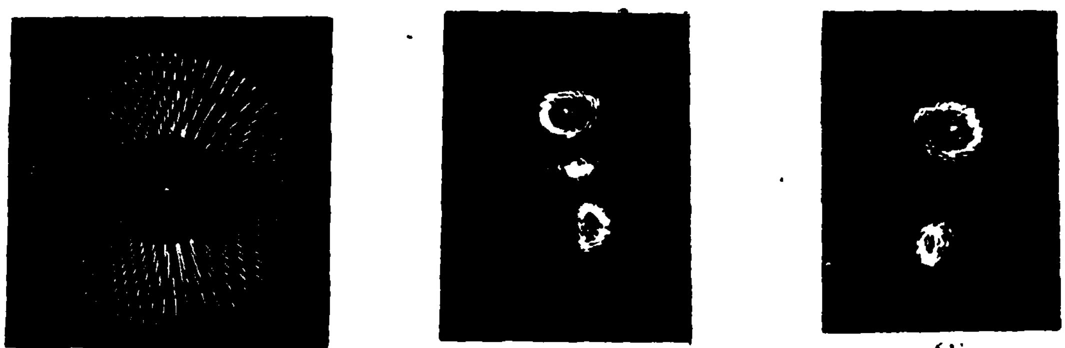


Fig. 4.17 a) Two cylinder target in anechoic chamber on rotating pedestal. b) Hologram of target measured between 5.3 and 16 GHz corrected for range and system response; 128 lines, 64 points/line. c) Optical Fourier transform of hologram. c) Optical Fourier transform without zero order term.

first of these was a single cylinder mounted off axis as shown in fig.4.18a. This cylinder was the same as the others used and the frequency range and angular sweep were identical to that of the two cylinder target. The hologram and reconstructions are shown in figs.4.18 b,c,d. The final target was the two off axis cylinder target pictured in fig.4.19a. The frequency diversity hologram and transforms are in figs.4.19 b,c,d.



(a)



(b) (c) (d)

Fig. 4.18 a) Single cylinder off-axis target and position in anechoic chamber. b) Experimental hologram of target; 6.3-16 GHz; 128 lines, 64 points/line; corrected for range and system response. c) Optical Fourier transform of hologram. d) Optical Fourier transform without zero order term.

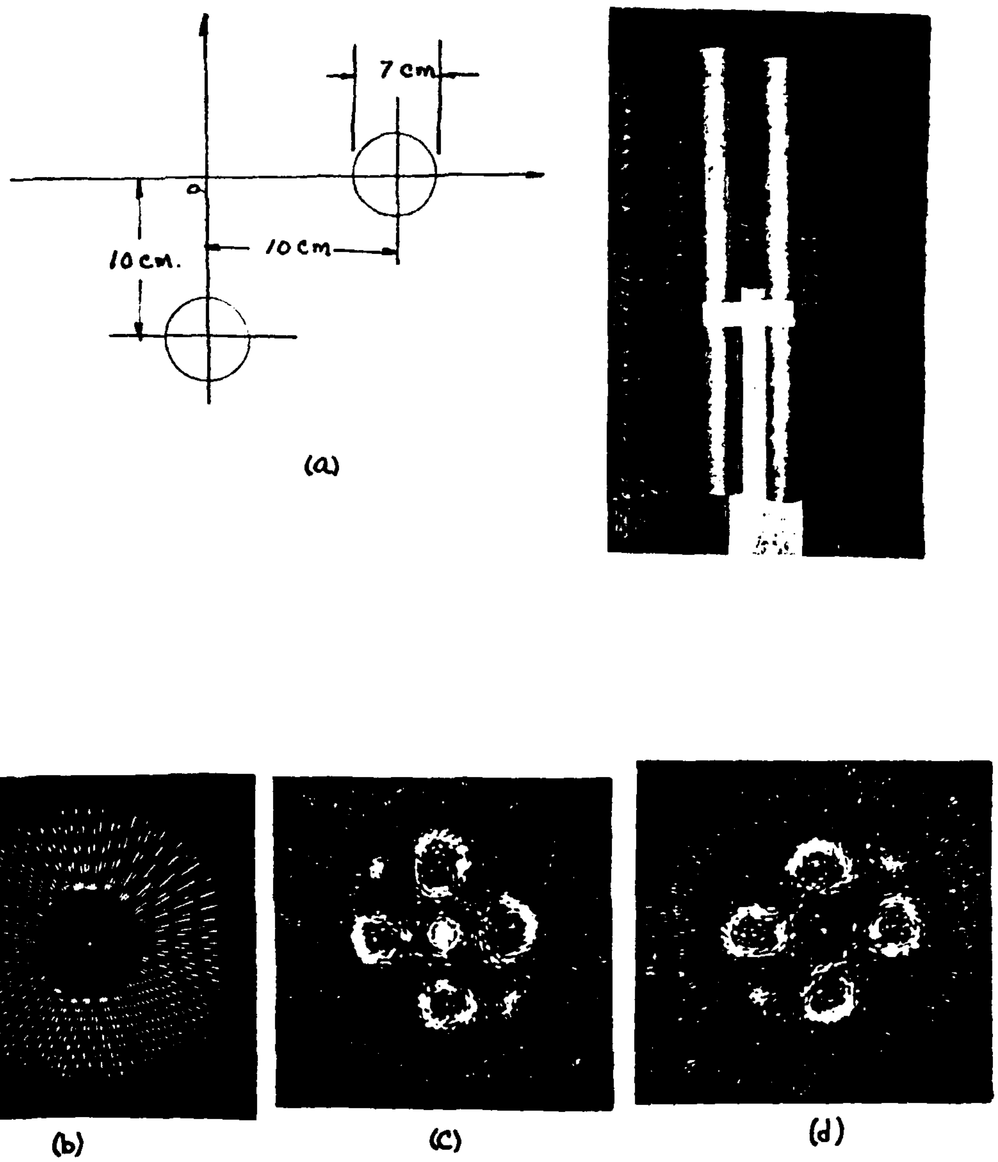


Fig. 4.19 a) Two cylinder off-axis target geometry and position in anechoic chamber. corrected for range and system response. c) Optical Fourier transform of hologram. d) Optical Fourier transform without zero order term.

V Conclusion

This thesis has described an automated swept frequency measuring system.This system may be used for radar cross section measurement, antenna pattern measurement and swept frequency holography. The system has a useful range of 5.0-17.0 GHz in which amplitude and phase of the scattered microwaves from targets in the anechoic chamber of the Graduate Research Center may be recorded and stored. A DEC MINC LSI-11/2 completely automates the data acquisition process. A complete error correction algorithm was implemented using the data storage and processing capabilities of the minicomputer.

The effect of range phase shift on swept frequency holograms was investigated and various techniques for its removal were investigated. It is believed that a TDR system for range phase removal is required for implementation of a practical radar system. This system must have extremely high resolution for coherent imaging. The relationship between TDR system bandwidth, receiver channel bandwidth and resolution was derived:

$$\text{Resolution} = \frac{\sigma_0 c}{\Delta f \, 2\pi} = \frac{\sqrt{2 N_0 B}\, c}{4\pi A \, \Delta f} \qquad 3.22$$

where (Δf) is the imaging bandwidth, (R) the range uncertainty, B the receiver channel bandwidth and N_0 the noise power spectral density.

Simulations were performed for the scattering of various radar targets which include the conducting sphere,

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where (Δf) is the imaging bandwidth, (R) the range uncertainty, B the receiver channel bandwidth and N_0 the noise power spectral density.

Simulations were performed for the scattering of various radar targets which include the conducting sphere,

infinite cylinder and combinations of these. The holograms recorded from these analytical results reconstruct the targets extremely well and set a goal for practical system performance. An expression was derived for the scattering of N spherical/cylindrical cylinders in a plane passing through their centers:

$$R\{E_s\} = \sum_n \cos\{kz a_n - k l_n \sin(\theta + \theta_n)\} \qquad (4.17)$$

where l is the distance from the axis of rotation (θ_n) the angle relative to some reference for the target angular position and a the target radius.

Finally experimental swept frequency holograms were generated using a rotating pedestal under computer control to scan the target in one dimension. The experiments done indicate the feasibility of implementing a practical holographic radar system. The holograms obtained for various targets agree well with theory even though the error correction and range phase shift removal techniques used were robust in nature. It is believed that better images are possible given that the error correction techniques previously outlined are implemented.

Further work can be done in testing the TDR techniques for their suitability for an imaging system. The system may also be expanded to include scanning in the ( ) direction to give true 3-D imaging capability. This may be implemented by adding a stepper motor controlled azimuthal scanner to the top of the rotating column.

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where l is the distance from the axis of rotation (θ_n) the angle relative to some reference for the target angular position and a the target radius.

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APPENDIX I

```
10 DIM A(25),B(25)
20 PRINT 'THIS PROGRAM WILL CALABRATE THE MICROWAVE SWEEPER' \ PRINT
30 PRINT 'ENTER NEW DATA (Y OR N)'
40 LINPUT D$
50 IF D$="Y" THEN  GO TO 120
60 PRINT 'WHAT FILE NAME'; \ LINPUT Z$
70 OPEN Z$ FOR INPUT AS FILE #1
80 FOR L=1 TO 25
90 INPUT #1,A(L),B(L)
100 NEXT L
110 GO TO 240
120 SEND('M1',4)
130 PRINT 'WHAT FILE NAME'; \ LINPUT Z$
140 OPEN Z$ FOR OUTPUT AS FILE #1
150 FOR I=1 TO 25
160 A(I)=500+375*(I-1)
170 C$='V'+STR$(A(I))+'E'+CHR$(13)+CHR$(10)
180 PRINT 'COMMAND: ';C$
190 SEND(C$,4)
200 PRINT 'INPUT THE COUNTER FREQUENCY';
210 INPUT B(I)
220 PRINT #1,A(I) \ PRINT #1,B(I)
230 NEXT I
240 V1=0 \ V2=0 \ C=0 \ N1=0 \ N2=0
250 FOR I=1 TO 25
260 N1=N1+A(I) \ N2=N2+B(I) \ V1=V1+A(I)^2 \ V2=V2+B(I)^2 \ C=C+A(I)*B(I)
270 NEXT I
280 FOR J=1 TO 25 \ PRINT A(J),B(J) \ NEXT J
290 PRINT 'CONTINUE FOR GRAPH (RETURN)' \ LINPUT Z$
300 DISPLAY+CLEAR
310 GRAPH('LINES,BRANDS',25,A(1),B(1))
320 LABEL('UNDERLINE','**** SWEEPER CALABRATION ****',,1)
330 PRINT 'CONTINUE (RETURN)' \ LINPUT Z$
340 DISPLAY+CLEAR
350 N1=N1/25 \ N2=N2/25 \ C=C/25 \ V1=V1/25 \ V2=V2/25
360 PRINT 'MUX','MUY','VARX','VARY','COVXY'
370 PRINT N1,N2,V1,V2,C
380 M=(C-N1*N2)/(V1-N1^2)
390 PRINT  \ PRINT
400 PRINT 'SLOPE=';M
410 PRINT
420 C=N2-M*N1
430 PRINT 'INTERCEPT=';C
440 N=25
450 Z1=0 \ Z2=0 \ Z3=0 \ Z4=0 \ Y1=0 \ Y2=0 \ Y3=0
460 FOR I=1 TO 25
470 Z1=Z1+A(I) \ Z2=Z2+A(I)^2 \ Z3=Z3+A(I)^3 \ Z4=Z4+A(I)^4
480 Y1=Y1+B(I) \ Y2=Y2+A(I)*B(I) \ Y3=Y3+A(I)^2*B(I)
490 NEXT I
500 PRINT "Z1","Z2","Z3","Z4"
510 PRINT Z1,Z2,Z3,Z4
520 PRINT  \ PRINT
530 PRINT 'Y1','Y2','Y3'
540 PRINT Y1,Y2,Y3
550 PRINT  \ PRINT
560 D=N*(Z2*Z4-Z3^2)-Z1*(Z1*Z4-Z2*Z3)+Z2*(Z1*Z3-Z2^2)
570 B0=Y1*(Z2*Z4-Z3^2)-Y2*(Z1*Z4-Z2*Z3)+Y3*(Z1*Z3-Z2^2)
580 B1=N*(Y2*Z4-Y3*Z3)-Y1*(Z1*Z4-Z2*Z3)+Z2*(Z1*Y3-Z2*Y2)
590 B2=N*(Z2*Y3-Z3*Y2)-Z1*(Z1*Y3-Z2*Y2)+Y1*(Z1*Z3-Z2^2)
600 B0=B0/D \ B1=B1/D \ B2=B2/D
610 PRINT 'B2','B1','B0'
620 PRINT B2,B1,B0
630 PRINT  \ PRINT
640 PRINT 'DO YOU WANT TO TEST THE DATA'
650 INPUT A$ \ IF A$='N' THEN  GO TO 1020
660 PRINT 'THIS IS A TEST OF THE PREDICTION CAPABILITIES OF THE INTERPOLAT
670 PRINT 'FUNCTIONS  INPUT THE VOLTAGE IN MILLIVOLTS. TO TERMINATE ENTER
680 PRINT 'NUMBER GREATER THAN 10000.'
690 SEND("M1",4)
700 PRINT  \ PRINT
710 PRINT 'INPUT THE VOLTAGE IN MV.'
720 INPUT A \ IF A>9999 THEN  GO TO 820
730 A$="V"+STR$(A)+"E"+CHR$(13)+CHR$(10)
740 SEND(A$,4)
750 F1=B0+B1*A+B2*A^2
760 F=M*A+C
770 PRINT  \ PRINT 'QUADRATIC FIT: ';F1
780 PRINT 'LINEAR FIT: ',TAB(14);F
790 PRINT
800 GO TO 710
810 PRINT  \ PRINT
820 PRINT  \ PRINT 'THIS PART OF THE PROGRAM WILL GENERATE THE ENTERED FRE
830 PRINT 'THE RANGE IS FROM 2.005-17.970 GHZ.  ENTER 0 TO TERMINATE.'
840 PRINT 'HIT RETURN FOR QUADRATIC FIT'
850 PRINT 'INPUT FREQUENCY IN GHZ'
860 PRINT
870 INPUT F \ IF F=0 THEN  GO TO 1020
880 V=(F-C)/M
890 V1=(-B1+SQR(B1^2-4*B2*(B0-F)))/(2*B2)
900 IF INT(10*V1)-10*INT(V1)>5 THEN V1=V1+1
910 IF INT(10*V)-10*INT(V)>5 THEN V=V+1
920 V1=INT(V1)
930 PRINT
940 V=INT(V)
950 A$='V'+STR$(V)+"E"+CHR$(13)+CHR$(10)
960 SEND(A$,4) \ PRINT 'FREQUENCY GENERATED FROM LINEAR FIT'
970 A$='V'+STR$(V1)+"E"+CHR$(13)+CHR$(10)
980 LINPUT Z$
  990 SEND(A$,4)
1000 PRINT 'FREQUENCY GENERATED FROM QUADRATIC FIT' \ PRINT
1010 GO TO 850
1020 CLOSE #1
1030 S=0 \ S1=0
1040 FOR I=1 TO 25
1050 S=S+(B(I)-(M*A(I)+C))^2
1060 S1=S1+(B(I)-(B0+B1*A(I)+B2*A(I)^2))^2
1070 NEXT I
1080 S=S/25 \ S1=S1/25
1090 PRINT  \ PRINT 'STANDARD DEVIATION FOR THE LINEAR FIT: ',SQR(S),"  GHZ
1100 PRINT  \ PRINT 'STANDARD DEVIATION FOR THE QUADRATIC FIT: ',SQR(S1),"
1110 END
```

```
FORTRAN IV      V02.1-1     THU 09-AUG-79 00:36:32                    PAGE 001
0001            PROGRAM SYSRES
           C
           C    VERSION 1.2
           C
           C    THIS PROGRAM WILL GENERATE THE SYSTEM RESPONSE USING THE
           C    SUBROUTINES FOR PAD, ISOLATION, TRANSFER FUNCTION AND
           C    ANTENNA RESPONCE GENERATION AND REMOVAL.  THE END RESULT IS A
           C    FILE WITH NORMALIZED INTEGERS WITH THE SYSTEM REFONSE.  FILES
            C    ARE GENERATED AT EACH STEP YIELDING A MODULAR PROCEDURE IN
           C    THIS PROCESS.  HENCE A COMPONANT OF THE SYSTEM COULD BE
           C    CHANGED WITH OUT HAVING TO START FROM THE BEGINNING.  FOR
           C    EXAMPLE A DIFFERENT ANTENNA COULD BE SUBSTITUTED AND THE
           C    SYSTEM RESPONSE COULD BE MEASURED WITHOUT HAVING TO START
           C    FROM THE BEGINNING WITH THE MEASUREMENT OF THE PAD
            C    CHARACTERISTICS.
           C
           C
           C
0002            COMMON/PADA/IAMPAD, IPHA, IFLAG, FSTART, FEND, STEP, NPOINT, NSAMP
0003            COMMON/ISTA/IAMP2, IPH2, IFLAG2, NSAMP2
0004            COMMON/TRANSA/IAMP3, IPH3, IFLAG3, NSAMP3, IAMP4, IPH4
0005            COMMON/ANTA/IAMP5, IPH5, IFLAG4, NSAMP4, IAMP6, IPH6
           C
           C
0006            INTEGER IAMPAD(512), IPHA(512), IAMP2(512), IPH2(512), IAMP3(512)
0007            INTEGER IPH3(512), IAMP4(512), IPH4(512), IPH5(512), IAMP5(512)
0008            INTEGER IPH6(512), IAMP6(512)
           C
           C
0009            BYTE A
0010            TYPE 900
0011            TYPE 801
0012            ACCEPT *, IUNIT
0013            TYPE 907
0014             ACCEPT *, IFLAG
0015            IF (IFLAG) 10,10,20
0016     10     TYPE 908
0017            ACCEPT *, NSAMP
0018     20     CALL PAD
0019            TYPE 901
0020            ACCEPT 700, A
0021            IF (A.EQ.'N') GO TO 200
0023            WRITE(IUNIT, 902)
0024            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0025            WRITE(IUNIT, 903)
0026            DO 100 K=1, NPOINT
0027            AMPLIT=FLOAT(IAMPAD(K))*.05
0028             PHASE=FLOAT(IPHA(K))*.25
0029            FREQ=FSTART+FLOAT(K-1)*STEP
0030            WRITE(IUNIT, 800)K, FREQ, AMPLIT, PHASE
0031    100     CONTINUE
0032    200     TYPE 909
0033            ACCEPT *, IFLAG2
0034            IF (IFLAG2) 210,210,220
FORTRAN IV      V02.1-1     THU 09-AUG-79 00:36:32                    PAGE 002
0035    210     TYPE 908
0036            ACCEPT *, NSAMP2
0037    220     CALL IST
0038            TYPE 901
0039            ACCEPT 700, A
0040            IF (A.EQ.'N') GO TO 300
0042            WRITE(IUNIT, 904)
0043            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0044            WRITE(IUNIT, 903)
0045            DO 250 K=1, NPOINT
0046            AMPLIT=FLOAT(IAMP2(K))*.05
0047            PHASE=FLOAT(IPH2(K))*.25
0048            FREQ=FSTART+FLOAT(K-1)*STEP
0049            WRITE(IUNIT, 800)K, FREQ, AMPLIT, PHASE
0050    250     CONTINUE
0051    300     TYPE 910
0052            ACCEPT *, IFLAG3
0053            IF (IFLAG3) 310,310,320
0054    310     TYPE 908
0055            ACCEPT *, NSAMP3
0056    320     CALL TRANS
0057            TYPE 901
0058            ACCEPT 700, A
0059            IF (A.EQ.'N') GO TO 400
0061            WRITE(IUNIT, 912)
0062            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0063            WRITE(IUNIT, 903)
0064            DO 330 K=1, NPOINT
0065            AMPLIT=FLOAT(IAMP3(K))*.05
0066            PHASE=FLOAT(IPH3(K))*.25
0067            FREQ=FSTART+FLOAT(K-1)*STEP
0068            WRITE(IUNIT, 800)K, FREQ, AMPLIT, PHASE
0069    330     CONTINUE
0070            WRITE(IUNIT, 905)
0071            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0072            WRITE(IUNIT, 903)
0073            DO 350 K=1, NPOINT
0074            AMPLIT=FLOAT(IAMP4(K))*.05
0075            PHASE=FLOAT(IPH4(K))*.25
0076            FREQ=FSTART+FLOAT(K-1)*STEP
0077            WRITE(IUNIT, 800)K, FREQ, AMPLIT, PHASE
0078    350     CONTINUE
0079    400     TYPE 911
0080            ACCEPT *, IFLAG4
0081            IF (IFLAG4) 410,410,420
0082    410     TYPE 908
0083            ACCEPT *, NSAMP4
0084    420     CALL ANTEN
0085            TYPE 901
0086            ACCEPT 700, A
0087            IF (A.EQ.'N') GO TO 500
0089            WRITE(IUNIT, 913)
0090            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0091            WRITE(IUNIT, 903)
FORTRAN IV      V02.1-1     THU 09-AUG-79 00:36:32                    PAGE 003
0092            DO 430 K=1, NPOINT
0093            AMPLIT=FLOAT(IAMP5(K))*.05
0094            PHASE=FLOAT(IPH5(K))*.25
0095            FREQ=FSTART+FLOAT(K-1)*STEP
0096            WRITE(IUNIT, 800)K, FREQ, AMPLIT, PHASE
0097    430     CONTINUE
0098            WRITE(IUNIT, 906)
0099            WRITE(IUNIT, 802)FSTART, FEND, STEP, NPOINT
0100            WRITE(IUNIT, 903)
0101            DO 450 K=1, NPOINT
0102            AMPLIT=FLOAT(IAMP6(K))*.05
```

```
0103          PHASE=FLOAT(IPH6(K))*.25
0104          FREQ=FSTART+FLOAT(K-1)*STEP
0105          WRITE(IUNIT,800)K,FREQ,AMPLIT,PHASE
0106    450   CONTINUE
0107    500   RETURN
        C
        C    *********** FORMAT STATMENTS ***********************
        C
        C
0108    900   FORMAT(/1X,'*********** WELCOME TO THE SYSTEM RESPONSE
             1GENERATION SYSTEM ***********')
0109    901   FORMAT(/'$','LIST RESPONSE DATA (Y OR N)?')
0110    902   FORMAT(///////1X,'***** PAD RESPONSE DATA *****'//)
0111    903   FORMAT(//1X,75('*')/12X,'POINT #',5X,'FREQUENCY',7X,
             1'AMPLITUDE DB.  ',5X,'PHASE DEGREES'/1X,75('*')/)
0112    904   FORMAT(///////1X,'***** ISOLATION OF NETWORK ANALYZER *****
             1'//)
0113    905   FORMAT(///////1X,'***** CORRECTED TRANSFER FUNCTION OF
             1SYSTEM *****'//)
0114    906   FORMAT(///////1X,'***** CORRECTED ANTENNA SYSTEM CLUTTER
             1 *****'//)
0115    907   FORMAT(/'$','ENTER PAD RESPONSE FILE FLAG (0=>NEW 1=>OLD)  : ')
0116    908   FORMAT(/'$','ENTER NUMBER OF SAMPLES PER FREQUENCY POINT.  : ')
0117    909   FORMAT(/'$','ENTER ISOLATION CHARACTERISTIC FILE FLAG
             1 (0=>NEW 1=>OLD) : ')
0118    910   FORMAT(/'$','ENTER TRANSFER FUNCTION FILE FLAG (0=>NEW 1=>OLD)
             1 : ')
0119    911   FORMAT(/'$','ENTER ANTENNA SYSTEM RESPONSE FILE FLAG (0=>NEW
             1 1=>OLD) : ')
0120    912   FORMAT(///////1X,'***** UNCORRECTED TRANSFER FUNCTION OF
             1SYSTEM *****'//)
0121    913   FORMAT(///////1X,'***** UNCORRECTED ANTENNA SYSTEM RESPONSE
             1 *****'//)
0122    700   FORMAT(A1)
0123    800   FORMAT(10X,I7,5X,1PG15.7,3X,1PG15.7,3X,1PG15.7)
0124    801   FORMAT(/'$','ENTER LOGICAL UNIT FOR OUTPUT (7=>TT. 2=>LP.)
             1 : ')
0125    802   FORMAT(/15X,'STARTING FREQUENCY GHZ:   ',1PG15.7/15X,
             1'ENDING FREQUENCY IN GHZ:  ',1PG15.7/15X,'FREQUENCY STEP GHZ.
             2,1PG15.7/15X,'NUMBER OF STEPS:   ',I7)
0126          STOP
0127          END
```

FORTRAN IV   STORAGE MAP FOR PROGRAM UNIT SYSRES
LOCAL VARIABLES, .PSECT $DATA, SIZE = 000070 (28. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
A	L*1	000032	AMPLIT	R*4	000040	FREQ	R*4	000050
IUNIT	I*2	000034	K	I*2	000036	PHASE	R*4	000044

COMMON BLOCK /PADA /, SIZE = 004022 (1033. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IAMPAD	I*2	000000	IPHA	I*2	002000	IFLAG	I*2	004000
FSTART	R*4	004002	FEND	R*4	004006	STEP	R*4	004012
NPOINT	I*2	004016	NSAMP	I*2	004020			

COMMON BLOCK /ISTA /, SIZE = 004004 (1026. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IAMP2	I*2	000000	IPH2	I*2	002000	IFLAG2	I*2	004000
NSAMP2	I*2	004002						

COMMON BLOCK /TRANSA/, SIZE = 010004 (2050. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IAMP3	I*2	000000	IPH3	I*2	002000	IFLAG3	I*2	004000
NSAMP3	I*2	004002	IAMP4	I*2	004004	IPH4	I*2	006004

COMMON BLOCK /ANTA /, SIZE = 010004 (2050. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IAMP5	I*2	000000	IPH5	I*2	002000	IFLAG4	I*2	004000
NSAMP4	I*2	004002	IAMP6	I*2	004004	IPH6	I*2	006004

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
IAMPAD	I*2	PADA	000000	002000 (512.)	(512)
IAMP2	I*2	ISTA	000000	002000 (512.)	(512)
IAMP3	I*2	TRANSA	000000	002000 (512.)	(512)
IAMP4	I*2	TRANSA	004004	002000 (512.)	(512)
IAMP5	I*2	ANTA	000000	002000 (512.)	(512)
IAMP6	I*2	ANTA	004004	002000 (512.)	(512)
IPHA	I*2	PADA	002000	002000 (512.)	(512)
IPH2	I*2	ISTA	002000	002000 (512.)	(512)
IPH3	I*2	TRANSA	002000	002000 (512.)	(512)
IPH4	I*2	TRANSA	006004	002000 (512.)	(512)
IPH5	I*2	ANTA	002000	002000 (512.)	(512)
IPH6	I*2	ANTA	006004	002000 (512.)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ANTEN	R*4	FLOAT	R*4	IST	I*2	PAD	R*4	TRANS	R*4


```
0001          SUBROUTINE PAD
        C
        C     VERSION 1.0
        C
        C     THIS ROUTINE WILL GENERATE THE CHARACTERISTIC OF THE PAD USED
        C     IN THE DETERMINATION OF THE SYSTEM RESPONSE IN THE FREQUENCY
        C     DIVERSITY IMAGING SYSTEM.  IT INVOLVES PLACING THE FLEXIBLE
        C     ARM WITH THE REFLECTION TRANSMISSION UNIT WITH THE ARM
        C     CONNECTED FROM THE UNKNOWN TO THE TRANSMISSION RETURN PORTS
        C     WITH A 6 DB PAD IN SERIES WITH THE ARM.  THE PRECISION APC-7
```

```
C     TO N ADAPTER IN SERIES. THE R-T UNIT OBTAINS RF DIRECTLY FROM
C     THE MICROWAVE SWEEPER. DATA IS OBTAINED IN THE FREQUENCY
C     REGION SPECIFIED AND IN THE INCREMENT SPECIFIED. AT THIS
C     POINT THE PAD WHASE CHARACTERISTIC IS DESIRED IS PLACED INTO
C     THE CIRCUIT AND THE SAME FREQUENCY POINTS ARE MEASURED. THEN
C     THE MAGNITUDE AND PHASE OF THE TWO MEASURMENTS ARE SUBTRACTED
C     AND THE RESULTANT VALUES ARE THE CHARACTERISTIC THE ONLY THE
C     PAD
C        IN THE EVENT THAT THE FILE CONTAINING THE PAD
C     RESPONSE ALREADY EXISTS THEN THE PROGRAM WILL FILL THE ARRAY
C      PAD WITH THE PAD RESPONSE
C
C
C     IAMPAD     ARRAY WITH AMPLITUDE OF PAD RESPONSE IN INTEGER FORM
C     IPHA       ARRAY WITH PHASE STORED IN INTEGER FORMAT RECIEVED
C     IFLAG      0=GENERATE NEW DATA
C        1=READ OLD DATA
C     FSTART     STARTING FREQUENCY FOR FREQ RESPONSE
C     FEND       ENDING FREQUENCY FOR FREQ RESPONSE
C     STEP       FREQUENCY STEP SIZE
C     NPOINT     NUMBER OF POINTS IN THE SWEEP
C     NSAMP      NUMBER OF SAMPLES TAKEN AT EACH FREQ POINT THEN
C        AVERAGED
C
C     THE CONVERSION FROM INTEGER TO REAL AMPLITUDE IS
C
C        AMPLITUDE=(IAMPAD(I)-2048)*.05
C
C        PHASE=(IPHA-2048)*.25
C
C        COMMON DECLARATION
C
C
      COMMON/PADA/IAMPAD,IPHA,IFLAG,FSTART,FEND,STEP,NPOINT,NSAMP
      INTEGER IAMPAD(512),IPHA(512)
C
      IF (IFLAG) 100,100,500      !NEW OR OLD DATA?
  100 TYPE 900          !PRINT FIRST INSTRUCTIONS
C
C     CREATE SEQUENTIAL ACCESS ASCII FILE USING SIMPLE LIST NOT
C     FORTRAN CARRAIGE CONTROL. THE FILE WILL EXPAND AS
C     NECESSARY. THE RECORD SIZE IS 6 CHARACTERS. THE UNIT NUMBER IS
C     LOGICAL UNIT 12. THE NAME WILL BE ASSIGN USING THE ASSIGN
C     SUBROUTINE IN THE LIBRARY. THIS IS A NEW FILE ON THE DISC AND
FORTRAN IV     V02.1-1     THU 09-AUG-79 00:46:59          PAGE 002
C     WILL BE SAVED WHEN THE FILE IS CLOSED
C
C
C     USE ASSIGN SUBROUTINE TO GET NAME FOR FILE
C
      CALL ASSIGN(12,,-1,'NEW','NC',1,)
C
C     ***********************************************************
C        SECTION TO OBTAIN CHARACTERISTICS OF ARM
C        AND 6 DB PAD.NOT THE ACTUAL PAD TO BE MEASURED
C     ***********************************************************
C
      TYPE 901    'NUMBER OF POINTS IN SYSTEM RESPONSE
      ACCEPT *,NPOINT
      TYPE 902    'STARTING FREQUENCY IN GHZ
      ACCEPT *,FSTART
      CALL SWEEP(1,FSTART,1,4)
      TYPE 903    'ENDING FREQUENCY IN GHZ
      ACCEPT *,FEND
      TYPE 904
      PAUSE
      STEP=(FEND-FSTART)/FLOAT(NPOINT)
      DO 200 K=1,(NPOINT)
      FREQ=FSTART+FLOAT(K-1)*STEP
      CALL SWEEP(1,FREQ,1,4)
      CALL PHAMP2(IA,IP,NSAMP)
      IAMPAD(K)=IA-2048
      IPHA(K)=IP-2048
  200 CONTINUE
      CALL SWEEP(1,FSTART,1,4)
      TYPE 905
      PAUSE
      DO 300 K=1,NPOINT
      FREQ=FSTART+FLOAT(K-1)*STEP
      CALL SWEEP(1,FREQ,1,4)
      CALL PHAMP2(IA,IP,NSAMP)
      IA=IA-2048
      IP=IP-2048
      IAMPAD(K)=IA-IAMPAD(K)
      IPHA(K)=IP-IPHA(K)
      IF (IPHA(K) GT 720) IPHA(K)=IPHA(K)-1440
      IF (IPHA(K) LT -720) IPHA(K)=IPHA(K)+1440
  300 CONTINUE
      CALL SWEEP(10,FREQ,1,4)      !RESET IEEE BUS
      WRITE(12,*) FSTART
      WRITE(12,*) FEND
      WRITE(12,*) NPOINT
      DO 400 K=1,NPOINT
      WRITE(12,*) IAMPAD(K)
      WRITE(12,*) IPHA(K)
  400 CONTINUE
      CALL CLOSE(12)
      GO TO 700
C
FORTRAN IV     V02.1-1     THU 09-AUG-79 00:46:59          PAGE 003
C     ***********************************************************
C        THIS SECTION WILL READ AN OLD PAD RESPONSE
C     ***********************************************************
C
  500 TYPE 906
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      STEP=(FEND-FSTART)/FLOAT(NPOINT)
      DO 600 K=1,NPOINT
      READ(12,*) IAMPAD(K)
      READ(12,*) IPHA(K)
  600 CONTINUE
      CALL CLOSE(12)
  700 RETURN
  900 FORMAT(/'$','ENTER THE PAD RESPONSE FILE NAME  ')
  901 FORMAT(//'$','ENTER NUMBER OF POINTS IN PAD RESPONSE  ')
  902 FORMAT(//'$', ENTER START FREQUENCY IN GIGAHERTZ  ')
  903 FORMAT(//'$','ENTER ENDING FREQUENCY IN GIGAHERTZ  ')
  904 FORMAT(//1X,'CONNECT THE FLEXIBLE ARM PLUS 6 DB PAD ,N',
```

```
      1' SERIES',/' AND CONNECT FROM THE UNKNOWN TO THE RETURN',
      2' PORT ON THE NETWORK ANALYZER')
0067  905  FORMAT(//1X,'CONNECT THE DESIRED PAD IN SERIES WITH THE',
      1' 6 DB PAD')
0068  906  FORMAT('$','ENTER THE OLD PAD RESPONSE FILE NAME   ')
0069       END
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT PAD

LOCAL VARIABLES, PSECT $DATA, SIZE = 000044 (18. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
FREQ	R*4	000024	IA	I*2	000030	IP	I*2	000032
K	I*2	000022						

COMMON BLOCK /PADA /, SIZE = 004022 (1033. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IAMPAD	I*2	000000	IPHA	I*2	002000	IFLAG	I*2	004000
FSTART	R*4	004002	FEND	R*4	004006	STEP	R*4	004012
NPOINT	I*2	004016	NSAMP	I*2	004020			

LOCAL AND COMMON ARRAYS

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
IAMPAD	I*2	PADA	000000	002000 (512)	(512)
IPHA	I*2	PADA	002000	002000 (512)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	CLOSE	R*4	FLOAT	R*4	PHAMP2	R*4	SWEEP	R*4


```
0001       SUBROUTINE IST
      C
      C    VERSION 1.3
      C
      C    THIS SUBROUTINE WILL MEASURE THE ISOLATION BETWEEN THE TWO
      C    CHANNELS OF THE NETWORK ANALYZER  THE FREQUENCY RANGE AND
      C    THE NUMBER OF STEPS WILL BE PASSED THROUGH COMMON BLOCK
      C    PADA  THE OUTPUT WILL BE THROUGH COMMON BLOCK ISTA  THE
      C    CABLES TO BE USED IN THE ACTUAL MEASUREMENT OF THE IMAGING
      C    SYSTEM ARE TERMINATED IN THEIR CHARACTERISTIC IMPEDENCE AND
      C    THE MAGNITUDE AND PHASE OF THE LEAKAGE SIGNAL ARE MEASURED
      C    AT THE SAME GAIN OF THE N/A FRONT PANEL AS THE SYSTEM
      C    MEASUREMENTS
      C
      C    IAMP2     ARRAY WITH AMPLITUDE OF LEAKED SIGNAL
    C        IPH2      ARRAY WITH PHASE OF LEAKED SIGNAL
      C    IFLAG2    FLAG FOR OLD OR NEW DATA 0=>GENERATE NEW DATA
      C       1=>  READ OLD DATA
      C    NSAMP2    NUMBER OF SAMPLE POINTS TAKEN AT EACH FREQUENCY
      C
      C
0002       COMMON/PADA/IAMPAD,IPHA,IFLAG,FSTART,FEND,STEP,NPOINT,NSAMP
0003       COMMON/ISTA/IAMP2,IPH2,IFLAG2,NSAMP2
      C
      C
0004       INTEGER IAMPAD(512),IPHA(512),IAMP2(512),IPH2(512)
0005       IF(IFLAG2) 100,100,500
0006  100  TYPE 900
0007       PAUSE
0008       CALL SWEEP(1,FSTART,1,4)
0009       DO 200 K=1,NPOINT
0010       FREQ=FSTART+FLOAT(K-1)*STEP
0011       CALL SWEEP(1,FREQ,1,4)
0012       CALL PHAMP2(IA,IP,NSAMP2)
0013       IAMP2(K)=IA-2048
0014       IPH2(K)=IP-2048
0015  200  CONTINUE
0016       CALL SWEEP(10,FSTART,1,4)
0017       TYPE 901
0018       CALL ASSIGN(12,,-1,'NEW','NC',1,)
0019       WRITE(12,*) FSTART
0020       WRITE(12,*) FEND
0021       WRITE(12,*) NPOINT
0022       DO 300 K=1,NPOINT
0023       WRITE(12,*) IAMP2(K)
0024       WRITE(12,*) IPH2(K)
0025  300  CONTINUE
0026       CALL CLOSE(12)
0027       GO TO 700
0028  500  TYPE 902
0029       TYPE 903
0030       CALL ASSIGN(12,,-1,'OLD','NC',1)
0031       READ(12,*) FSTART
0032       READ(12,*) FEND
```



```
0033       READ(12,*) NPOINT
0034       STEP=(FEND-FSTART)/FLOAT(NPOINT)
0035       DO 600 K=1,NPOINT
0036       READ(12,*) IAMP2(K)
0037       READ(12,*) IPH2(K)
0038  600  CONTINUE
```

```
0039          CALL CLOSE(12)
0040    700   RETURN
        C
        C
0041    900   FORMAT(//1X,'SUBROUTINE IST MEASURES AMPLITUDE AND PHASE FROM '
             1/1X,'THE NETWORK ANALYZER IN ORDER TO OBTAIN ITS DIRECTIVITY.'/
             21X,'CONNECT THE ANTENNA SYSTEM CABLES TERMINATED IN THEIR CHARA
             3TERISTIC IMPEDENCE.'/)
0042    901   FORMAT('$','ENTER THE NEW FILE NAME FOR THE ISOLATION DATA   ')
0043    902   FORMAT(//1X,'SUBROUTINE IST READS MAGNITUDE AND PHASE DATA ',
             1/1X,'FROM THE SPECIFIED DATA FILE.'//)
0044    903   FORMAT(///'$','ENTER THE OLD FILE NAME FOR THE ISOLATION DATA.
0045          END

FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT IST
LOCAL VARIABLES.  PSECT $DATA.  SIZE = 000036 (   15  WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

FREQ   R*4   000020     IA     I*2   000024     IP     I*2   000026

K      I*2   000016


COMMON BLOCK /PADA  /, SIZE = 004022 ( 1033  WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

IAMPAD I*2   000000     IPHA   I*2   002000     IFLAG  I*2   004000

FSTART R*4   004002     FEND   R*4   004006     STEP   R*4   004012

NPOINT I*2   004016     NSAMP  I*2   004020

COMMON BLOCK /ISTA  /, SIZE = 004004 ( 1026  WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

IAMP2  I*2   000000     IPH2   I*2   002000     IFLAG2 I*2   004000

NSAMP2 I*2   004002

LOCAL AND COMMON ARRAYS.

NAME     TYPE   SECTION OFFSET  ------SIZE----- DIMENSIONS
IAMPAD   I*2    PADA    000000  002000 (  512. ) (512)
IAMP2    I*2    ISTA    000000  002000 (  512. ) (512)
IPHA     I*2    PADA    002000  002000 (  512. ) (512)
IPH2     I*2    ISTA    002000  002000 (  512. ) (512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE

ASSIGN R*4    CLOSE  R*4    FLOAT  R*4    PHAMP2 R*4    SWEEP  R*4
```

```
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:03:11                PAGE 001
0001            SUBROUTINE TRANS
          C
          C     VERSION 1.3
          C
          C     THIS SUBROUTINE WILL FIND THE TRANSFER FUNCTION OF THE CABLES
          C     AND THE NETWORK ANALYZER SYSTEM.  THE ISOLATION AND PAD
          C     CHARACTERISTICS ARE PASSED THROUGH COMMON TO THIS ROUTINE
          C     AT THAT POINT THE CABLES FROM THE TRANSMITTING AND RECIEVING
          C     ANTENNAS ARE CONNECTED TOGETHER THROUGH A PAD WHOSE RESPONSE
          C     IS ALREADY KNOWN.  THE TRANSFER CHARACTERISTIC IS THEN CAL-
          C     CULATED AND STORED
          C
          C     IAMP3       ARRAY CONTAINING UNCORRECTED TRANSFER CHARACTERISTIC
          C       AMPLITUDE
          C     IPH3        ARRAY CONTAINING UNCORRECTED TRANSFER
          C       CHARACTERISTIC PHASE
          C     IAMP4.      ARRAY CONTAINING CORRECTED AMP TRANS CHAR
          C     IPH4.       ARRAY CONTAINING CORRECTED TRANS PHASE CHAR.
          C     NSAMP3      NUMBER OF SAMPLES AT EACH FREQUENCY POINT
          C     IFLAG3      FLAG FOR OLD OR NEW DATA 0=>NEW 1=>OLD DATA
          C
          C     T/R=(C+P*G)/R
          C
          C     T: RECEIVER CHANNEL SIGNAL
          C     R: REFERENCE CHANNEL SIGNAL.
          C     C: NETWORK ANALYZER REFERENCE-TO-RECEIVER CHANNEL
          C        ISOLATION
          C     P: PAD CHARACTERISTIC
          C     G: FREQUENCY CHARACTERISTICS(TRANSFER FUNCTION) OF
          C        THE RECEIVER CHANNEL AND ITS CABLE.
          C
          C     CORRECT THIS FOR THE REFERENCE TO RECEIVER CHANNEL ISOLATION
          C     AND THE PAD FREQUENCY CHARACTERISTICS
          C
          C
          C     C/R => M1   MEASURMENT OF REFERENCE TO RECEIVER ISOLATION
          C                 OVER REFERENCE
          C
          C    (C+P*G) => M2       MEASURMENT OF TRANSFER FUNCTION PLUS PAD AND
          C                 ISOLATION
          C
          C     G/R=(M2-M1)/P      SUBTRACT PAD AND ISOLATION REPONSES
          C                        AND STORE
          C
0002            COMMON/PADA/IAMPAD, IPHA, IFLAG, FSTART, FEND, STEP, NPOINT, NSAMP
0003            COMMON/ISTA/IAMP2, IPH2, IFLAG2, NSAMP2
0004            COMMON/TRANSA/IAMP3, IPH3, IFLAG3, NSAMP3, IAMP4, IPH4
0005            INTEGER IAMPAD(512), IPHA(512), IAMP2(512), IPH2(512), IAMP3(512),
               1IPH3(512), IAMP4(512), IPH4(512)
          C
          C
0006            IF (IFLAG3) 100,100,500
0007    100     TYPE 900
0008            TYPE 901
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:03:11                PAGE 002
0009            PAUSE
0010            CALL SWEEP(1,FSTART,1,4)
0011            DEG=3.1415926/180.
```

```
      DO 200 K=1,NPOINT
      FREQ=FSTART+FLOAT(K-1)*STEP
      CALL SWEEP(1,FREQ,1,4)
      CALL PHAMP2(IA,IP,NSAMP3)
      IAMP3(K)=(IA-2048)
      IPH3(K)=(IP-2048)
200   CONTINUE
      CALL SWEEP(10,FSTART,1,4)
      TYPE 902
      CALL ASSIGN(12,,-1,'NEW','NC',1,)
C
C     STORE THE UNCORRECTED DATA
C
C
      WRITE(12,*) FSTART
      WRITE(12,*) FEND
      WRITE(12,*) NPOINT
      DO 300 K=1,NPOINT
      WRITE(12,*) IAMP3(K)
      WRITE(12,*) IPH3(K)
300   CONTINUE
      CALL CLOSE(12)
C
C
C     OPEN FILE WITH CORRECTED DATA
C
C
      TYPE 903
      CALL ASSIGN(12,,-1,'NEW','NC',1,)
      WRITE(12,*) FSTART
      WRITE(12,*) FEND
      WRITE(12,*) NPOINT
C
C     GENEREATE CORRECTED DATA AND STORE
C
      PI=3 1415926
      DO 400      K=1,NPOINT
C
C     CONVERT TO DEGREES AND DB
C
      PIST= 25*FLOAT(IPH2(K))*DEG
      ADBIST= 05*FLOAT(IAMP2(K))
      PTRAN= 25*FLOAT(IPH3(K))*DEG
      ADBTRN= 05*FLOAT(IAMP3(K))
C
C     CONVERT TO WATTS
C
      AIST=10 **(ADBIST/10 )
      ATRN=10 **(ADBTRN/10 )
C
C     FIND REAL AND IMAGINARY PARTS
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:03:11                PAGE 003
C
      ATRNX=ATRN*COS(PTRAN)
      ATRNY=ATRN*SIN(PTRAN)
      AISTX=AIST*COS(PIST)
      AISTY=AIST*SIN(PIST)
C
C     SUBTRACT ISOLATION FROM TRANSFER+ISOLATION
C
      ATEMPX=ATRNX-AISTX
      ATEMPY=ATRNY-AISTY
C
C     CONVERT BACK TO DEGREES AND DB
C
      ATEMP=SQRT(ATEMPX**2+ATEMPY**2)
      TPHASE=ATAN2(ATEMPY,ATEMPX)
C
C     DIVIDE BY PAD RESPONSE TO REMOVE IT FROM TRANSFER FUNCTION
C
      ADBTEM=10.*ALOG10(ATEMP)
      APAD=.05*FLOAT(IAMPAD(K))
      ATRANS=ADBTEM-APAD
      IAMP4(K)=IFIX(20.*ATRANS)
      PTRANS=TPHASE-(.25*FLOAT(IPHA(K))*DEG)
      IF (PTRANS .GT. PI) PTRANS=PTRANS-2.*PI
      IF (PTRANS .LT. -PI) PTRANS=PTRANS+2.*PI
      IPH4(K)=IFIX(4.*(PTRANS/DEG))
      WRITE(12,*) IAMP4(K)
      WRITE(12,*) IPH4(K)
400   CONTINUE
      CALL CLOSE(12)
      GO TO 700
500   TYPE 905
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      DO 600 K=1,NPOINT
      READ(12,*) IAMP3(K)
      READ(12,*) IPH3(K)
600   CONTINUE
      CALL CLOSE(12)
      TYPE 904
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      DO 650 K=1,NPOINT
      READ(12,*) IAMP4(K)
      READ(12,*) IPH4(K)
650   CONTINUE
      CALL CLOSE(12)
700   RETURN
900   FORMAT(//1X'SUBROUTINE TRANS DETERMINES THE TRANSFER  ',/1X,
     1'FUNCTION OF THE NETWORK ANALYZER AND CABLES.')
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:03:11                PAGE 004
901   FORMAT(//1X'CONNECT THE INPUT AND OUTPUT CABLES THROUGH A',
     1' PRECISION PAD ')
902   FORMAT(//1X,'ENTER THE NAME OF THE NEW FILE TO CONTAIN THE ',/
     1,'$','UNCORRECTED TRANSFER FUNCTION DATA:  ')
903   FORMAT(//1X,'ENTER THE NAME OF THE NEW FILE TO CONTAIN THE ',/
     1,'$','CORRECTED TRANSFER FUNCTION DATA:  ')
904   FORMAT(//1X,'ENTER THE NAME OF THE OLD FILE CONTAINING THE ',/
     1,'$','CORRECTED TRANSFER FUNCTION DATA:  ')
905   FORMAT(//1X,'ENTER THE NAME OF THE OLD FILE CONTAINING THE',/
     1,'$','UNCORRECTED TRANSFER FUNCTION DATA:  ')
      STOP
      END

FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT TRANS
```

```
FORTRAN IV      V02 1-1     THU 09-AUG-79 01:12:37               PAGE 001
0001          SUBROUTINE ANTEN
      C
      C       VERSION 1 4
      C
      C       THIS SUBROUTINE WILL MEASURE THE ANTENNA AND ROOM
      C       CHARACTERISTICS EXPLICITY. FIRST A MEASUREMENT
      C       INCLUDING THE SYSTEM CHARACTERISTICS IS TAKEN
      C       AND STORED AT EACH FREQUENCY. IN ADDITION THE
      C       ROOM CLUTTER AND ANTENNA CHARACTERISTICS ARE CALCULATED
      C       WHEN THE CABLE RESPONSE AND ISOLATION CHARACTERISTIC
      C       OF THE NETWORK ANALYZER ARE REMOVED.
      C
      C       G/R:        THE TRANSFER CHARACTERISTIC OF THE N/A FROM
      C          SUBROUTINE TRANS
      C
      C       T/R=(C+G*X)/R
      C       WHERE
      C          X:       RECEIVED SIGNAL FORM CROSS COUPLING AND
      C                   CLUTTER
      C          G:       TRANSFER FUNCTION OF N/A + CABLE
      C          R:       REFERENCE CHANNEL SIGNAL
      C          T/R.     RECEIVED MEASURMENT => M3
      C          M1:      ISOLATION MEASUMENT
      C
      C          X/R=(M3-M1)/(G/R)
      C
      C          ALL MEASURMENTS ARE RELATIVE TO THE REFERENCE
      C          CHANNEL SIGNAL IE. TRANSMITTED SIGNAL
      C
      C
0002          COMMON/PADA/IAMPAD, IPHA, IFLAG, FSTART, FEND, STEP, NPOINT, NSAMP
0003          COMMON/ISTA/IAMP2, IPH2, IFLAG2, NSAMP2
0004          COMMON/TRANSA/IAMP3, IPH3, IFLAG3, NSAMP3, IAMP4, IPH4
0005          COMMON/ANTA/IAMP5, IPH5, IFLAG4, NSAMP4, IAMP6, IPH6
      C
      C
0006          INTEGER IAMPAD(512), IPHA(512), IAMP2(512), IPH2(512), IAMP3(512)
0007          INTEGER IPH3(512), IAMP4(512), IPH4(512), IAMP5(512), IPH5(512)
0008          INTEGER IAMP6(512), IPH6(512)
      C
      C
0009          IF (IFLAG4) 100, 100, 500
0010    100   TYPE 900
0011          CALL SWEEP(1, FSTART, 1, 4)
0012          PAUSE
0013          DO 200 K=1, NPOINT
0014          FREQ=FSTART+FLOAT(K-1)*STEP
0015          CALL SWEEP(1, FREQ, 1, 4)
0016          CALL PHAMP2(IA, IP, NSAMP4)
0017          IAMP5(K)=IA-2048
0018          IPH5(K)=IP-2048
0019    200   CONTINUE
0020          CALL SWEEP(10, FSTART, 1, 4)
0021          TYPE 901
FORTRAN IV      V02 1-1     THU 09-AUG-79 01:12.37               PAGE 002
0022          CALL ASSIGN(12, , -1, 'NEW', 'NC', 1, )
0023          WRITE(12, *) FSTART
0024          WRITE(12, *) FEND
0025          WRITE(12, *) NPOINT
0026      DO 300 K=1, NPOINT
0027          WRITE(12, *) IAMP5(K)
0028          WRITE(12, *) IPH5(K)
0029    300   CONTINUE
0030          CALL CLOSE(12)
      C
      C*********************************************************************
      C
      C       THIS SECTION WILL CALCULATE THE SYSTEM CLUTTER
      C
      C*********************************************************************
      C
0031          PI=3.1415926
0032          DEG=PI/180.
0033          TYPE 902
0034          CALL ASSIGN(12, , -1, 'NEW', 'NC', 1, )
0035          WRITE(12, *) FSTART
0036          WRITE(12, *) FEND
0037          WRITE(12, *) NPOINT
0038          DO 400 K=1, NPOINT
0039          PIST=.25*FLOAT(IPH2(K))*DEG
0040          PANT=.25*FLOAT(IPH5(K))*DEG
0041          ADBIST=.05*FLOAT(IAMP2(K))
0042          ADBANT=.05*FLOAT(IAMP5(K))
0043          AIST=10.**(ADBIST/10.)
0044          AANT=10.**(ADBANT/10.)
0045          AISTX=AIST*COS(PIST)
0046          AISTY=AIST*SIN(PIST)
0047          AANTX=AANT*COS(PANT)
0048          AANTY=AANT*SIN(PANT)
      C
      C       SUBTRACT ISOLATION FROM ANTENNA RESPONSE
      C
0049          ATEMPX=AANTX-AISTX
0050          ATEMPY=AANTY-AISTY
      C
      C       CONVERT BACK TO PHASOR FORM
      C
0051          PTEMP=ATAN2(ATEMPY, ATEMPX)
0052          ATEMP=SQRT(ATEMPX**2+ATEMPY**2)
0053          ADBTEM=10.*ALOG10(ATEMP)
0054          ARES=ADBTEM-(.05*FLOAT(IAMP4(K)))
0055          PRES=PTEMP-(.25*FLOAT(IPH4(K))*DEG)
0056          IF (PRES.GT.PI)PRES=PRES-2.*PI
0058          IF (PRES.LT.-PI)PRES=PRES+2.*PI
0060          IPH6(K)=IFIX(4.*PRES/DEG)
0061          IAMP6(K)=IFIX(20.*ARES)
0062          WRITE(12, *)IAMP6(K)
0063          WRITE(12, *)IPH6(K)
0064    400   CONTINUE
FORTRAN IV      V02 1-1     THU 09-AUG-79 01:12:37               PAGE 003
0065          CALL CLOSE (12)
0066          GO TO 700
0067    500   TYPE 904
0068          CALL ASSIGN(12, , -1, 'OLD', 'NC', 1)
0069          READ(12, *) FSTART
0070          READ(12, *) FEND
0071          READ(12, *) NPOINT
0072          DO 600 K=1, NPOINT
```

```
      READ(12,*) IAMP5(K)
      READ(12,*) IPH5(K)
600   CONTINUE
      CALL CLOSE(12)
      TYPE 903
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      DO 650 K=1,NPOINT
      READ(12,*) IAMP6(K)
      READ(12,*) IPH6(K)
650   CONTINUE
      CALL CLOSE(12)
700   RETURN
C
C
C
900   FORMAT(//1X'SUBROUTINE ANTEN DETERMINES THE ANTENNA '
     1,'CHARACTERISTICS AND'/1X,'ANTENNA CROSS COUPLING '
     2///1X,'CONFIGURE THE SYSTEM IN ITS FINAL FORM')
901   FORMAT(//'$','ENTER THE ANTENNA SYSTEM RESPONSE NEW FILE
     1 NAME:  ')
902   FORMAT(/,'$','ENTER THE ANTENNA CLUTTER DATA FILE NAME.  ')
903   FORMAT(//'$','ENTER THE ANTENNA CLUTTER OLD FILE
     1 NAME.  ')
904   FORMAT(//'$','ENTER THE ANTENNA SYSTEM RESPONSE OLD FILE
     1 NAME.  ')
      STOP
      END
```

```
FORTRAN IV     STORAGE MAP FOR PROGRAM UNIT ANTEN
LOCAL VARIABLES,  PSECT $DATA, SIZE = 000216 (   71. WORDS)

NAME    TYPE  OFFSET    NAME    TYPE  OFFSET    NAME    TYPE  OFFSET

AANT    R*4   000110    AANTX   R*4   000124    AANTY   R*4   000130

ADBANT  R*4   000100    ADBIST  R*4   000074    ADBTEM  R*4   000154

AIST    R*4   000104    AISTX   R*4   000114    AISTY   R*4   000120

ARES    R*4   000160    ATEMP   R*4   000150    ATEMPX  R*4   000134

ATEMPY  R*4   000140    DEG     R*4   000060    FREQ    R*4   000044

IA      I*2   000050    IP      I*2   000052    K       I*2   000042

PANT    R*4   000070    PI      R*4   000054    PIST    R*4   000064

PRES    R*4   000164    PTEMP   R*4   000144


COMMON BLOCK /PADA  /, SIZE = 004022 ( 1033. WORDS)

NAME    TYPE  OFFSET    NAME    TYPE  OFFSET    NAME    TYPE  OFFSET

IAMPAD  I*2   000000    IPHA    I*2   002000    IFLAG   I*2   004000

FSTART  R*4   004002    FEND    R*4   004006    STEP    R*4   004012

NPOINT  I*2   004016    NSAMP   I*2   004020

  COMMON BLOCK /ISTA  /, SIZE = 004004 ( 1026  WORDS)

NAME    TYPE  OFFSET    NAME    TYPE  OFFSET    NAME    TYPE  OFFSET

IAMP2   I*2   000000    IPH2    I*2   002000    IFLAG2  I*2   004000

NSAMP2  I*2   004002

COMMON BLOCK /TRANSA/, SIZE = 010004 ( 2050. WORDS)

NAME    TYPE  OFFSET    NAME    TYPE  OFFSET    NAME    TYPE  OFFSET

IAMP3   I*2   000000    IPH3    I*2   002000    IFLAG3  I*2   004000

NSAMP3  I*2   004002    IAMP4   I*2   004004    IPH4    I*2   006004

COMMON BLOCK /ANTA  /, SIZE = 010004 ( 2050. WORDS)

NAME    TYPE  OFFSET    NAME    TYPE  OFFSET    NAME    TYPE  OFFSET

IAMP5   I*2   000000    IPH5    I*2   002000    IFLAG4  I*2   004000

NSAMP4  I*2   004002    IAMP6   I*2   004004    IPH6    I*2   006004

LOCAL AND COMMON ARRAYS:

NAME    TYPE   SECTION OFFSET  ------SIZE----- DIMENSIONS
IAMPAD  I*2    PADA    000000  002000 (  512.) (512)
IAMP2   I*2    ISTA    000000  002000 (  512 ) (512)
IAMP3   I*2    TRANSA  000000  002000 (  512.) (512)
IAMP4   I*2    TRANSA  004004  002000 (  512.) (512)
IAMP5   I*2    ANTA    000000  002000 (  512.) (512)
IAMP6   I*2    ANTA    004004  002000 (  512.) (512)
IPHA    I*2    PADA    002000  002000 (  512.) (512)
IPH2    I*2    ISTA    002000  002000 (  512 ) (512)
IPH3    I*2    TRANSA  002000  002000 (  512.) (512)
IPH4    I*2    TRANSA  006004  002000 (  512.) (512)
IPH5    I*2    ANTA    002000  002000 (  512.) (512)
IPH6    I*2    ANTA    006004  002000 (  512 ) (512)

FORTRAN IV     STORAGE MAP FOR PROGRAM UNIT ANTEN
SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME    TYPE  NAME    TYPE  NAME    TYPE  NAME    TYPE  NAME    TYPE

ALOG10  R*4   ASSIGN  R*4   ATAN2   R*4   CLOSE   R*4   COS     R*4

FLOAT   R*4   IFIX    I*2   PHAMP2  R*4   SIN     R*4   SQRT    R*4

SWEEP   R*4
```

```
0001          PROGRAM SPHERE
        C
        C     VERSION 1.2
        C
        C     THIS PROGRAM WILL TAKE EXPERIMENTAL DATA FOR THE SPHERE
        C     AND CORRECT IT FOR THE SYSTEM RESPONSE. IT WILL PRINT
        C     BOTH THE CORRECTED AND UNCORRECTED DATA AND FINNALY DISPLAY
        C     IT ON THE HIGH RESOLUTION CRT.
        C
        C     ALSO IT DESIRED IT WILL GENERATE IF DESIRED ANALYTICAL
        C     DATA FOR THE SPHERE AND STORE IT IN A FILE. IT WILL ALSO
        C     PRINT THIS DATA IF DESIRED TO A FILE AND ALSO DISPLAY IT ON
        C     THE HIGH RESOLUTION CRT MONITOR.
        C
        C
0002          COMMON/RANGE1/DIST,IRFLAG,IUNIT
0003          COMMON/OBJ/OBJA,OBJP,NSAMP2
0004          COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
        C
        C
0005          INTEGER OBJA(512),OBJP(512),TRANA(512)
0006          INTEGER TRANP(512),CLUTA(512),CLUTP(512),NPOINT,NSAMP2
0007          BYTE A
        C
        C
0008          TYPE 900
0009          TYPE 912
0010          ACCEPT *,IUNIT
        C
        C     THIS SECTION WILL GENERATE CORRECTED SPHERE DATA FROM
        C     EXPERIMENTAL DATA
        C
0011          TYPE 902
0012          CALL SYSINP
0013          STEP=(FEND-FSTART)/FLOAT(NPOINT)
0014          CALL SPHDAT
0015          TYPE 903
0016          ACCEPT 1000,A
0017          IF (A.EQ.'N') GO TO 220
0019          WRITE(IUNIT,904)
0020          WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0021          WRITE(IUNIT,906)
0022          DO 210 K=1,NPOINT
0023          AMPLIT=FLOAT(OBJA(K))*.05
0024          PHASE=FLOAT(OBJP(K))*.25
0025          FREQ=FSTART+FLOAT(K-1)*STEP
0026          WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0027    210   CONTINUE
0028    220   CALL CORREC
        C
        C     HERE LIST THE CORRECTED SPHERE DATA
        C
0029    250   TYPE 915
0030          ACCEPT 1000,A
```



```
0031          IF (A.EQ.'N') GO TO 280
0033          WRITE(IUNIT,909)
0034          WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0035          WRITE(IUNIT,906)
0036      DO 277 K=1,NPOINT
0037          IND1=K
0038          AMPLIT=FLOAT(OBJA(K))*.05
0039             PHASE=FLOAT(OBJP(K))*.25
0040          FREQ=FSTART+FLOAT(IND1-1)*STEP
0041          WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0042    277   CONTINUE
0043    280   CONTINUE
        C
        C     THIS SECTION WILL STORE THE CORRECTED DATA FOR SYSTEM RESPONSE
        C
0044          TYPE 802
0045          ACCEPT 1000,A
0046          IF (A.EQ.'N') GO TO 400

0048             TYPE 801
0049          CALL ASSIGN(20,,-1,'NEW','NC',)
0050          WRITE(20,*)FSTART
0051          WRITE(20,*)FEND
0052          WRITE(20,*)NPOINT
0053          DO 310 K=1,NPOINT
0054          WRITE(20,*)OBJA(K)
0055          WRITE(20,*)OBJP(K)
0056    310   CONTINUE
0057          CALL CLOSE(20)
        C
        C     THIS SECTION WILL CORRECT FOR RANGE
        C
0058    400   TYPE 914
0059          ACCEPT *,IRFLAG
0060          CALL RANGE
        C
0061          TYPE 913,DIST
0062          CALL RANCOR
0063          TYPE 916
0064          ACCEPT 1000,A
0065          IF (A.EQ.'N') GO TO 470
0067          WRITE(IUNIT,913)DIST
0068          WRITE(IUNIT,911)
0069          WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0070          WRITE(IUNIT,906)
0071          DO 410 K=1,NPOINT
0072          IND1=K
0073          AMPLIT=FLOAT(OBJA(K))*.05
0074          PHASE=FLOAT(OBJP(K))*.25
0075          FREQ=FSTART+FLOAT(IND1-1)*STEP
0076          WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0077    410   CONTINUE
        C
        C     THIS SECTION WILL STORE THE RANGE CORRECTED DATA
        C
```



```
        C
0078    470   TYPE 901
0079          ACCEPT 1000,A
0080          IF (A.EQ.'N') GO TO 500
0082          TYPE 800
0083          CALL ASSIGN(20,,-1,'NEW','NC',)
0084          WRITE(20,*)FSTART
```

```
0085          WRITE(20,*)FEND
0086     WRITE(20,*)NPOINT
0087          DO 460 K=1,NPOINT
0088          WRITE(20,*)OBJA(K)
0089          WRITE(20,*)OBJP(K)
0090   460    CONTINUE
0091          CALL CLOSE(20)
       C
       C      THIS SECTION WILL DISPLAY THE DATA
       C
0092   500    CONTINUE
       C
       C      FORMAT STATEMENTS
       C
0093   800    FORMAT(///,'$ENTER THE FILE NAME FOR THE RANGE
             1COORECTED DATA  ')
0094   801    FORMAT(///,'$ENTER THE FILE NAME FOR THE COORECTED DATA.  ')
0095   802    FORMAT(///,'$DO YOU WANT TO STORE THE CORRECTED DATA (Y OR N)
             1   ')
0096   900    FORMAT(////,'**** PROGRAM SPHERE ****')
0097   901    FORMAT(///,'$DO YOU WANT TO STORE THE RANGE CORRECTED
             1DATA (Y OR N) ? ')
0098   902    FORMAT(//,' THIS SECTION WILL GENERATE CORRECTED SPHERE DATA
             1FROM '/' EXPERIMENTAL DATA')
0099   903    FORMAT(//,'$PRINT THE UNCORRECTED DATA (Y OR N):   ')
0100   904    FORMAT(///////,'***** UNCORRECTED SPHERE DATA *****')
0101   905    FORMAT(/15X,'STARTING FREQUENCY GHZ:    ',1PG15.7/15X,
             1'ENDING FREQUENCY IN GHZ:   ',1PG15.7/15X,'FREQUENCY STEP GHZ.
             2,1PG15.7/15X,'NUMBER OF STEPS:   ',I7)
0102   906    FORMAT(//1X,75('*')/12X,'POINT #',5X,'FREQUENCY',7X,
             1'AMPLITUDE DB   ',5X,'PHASE DEGREES'/1X,75('*')/)
0103   907    FORMAT(10X,I7,5X,1PG15.7,3X,1PG15.7,3X,1PG15.7)
0104   909    FORMAT(///////,' ***** CORRECTED EXPERIMENTAL SPHERE
             1DATA *****')
0105   911    FORMAT(///////,' ***** EXPERIMENTAL SPHERE DATA CORRECTED
             1FOR RANGE *****').
0106   912    FORMAT(///'$','ENTER LOGICAL UNIT NUMBER FOR OUTPUT (7=>
             1TERMINAL)   ')
0107   913    FORMAT(////,' CALCULATED RANGE TO THE TARGET= ',1PG15.7,
             1' METERS')
0108   914    FORMAT(///,' ENTER THE RANGE CALCULATION FLAG'//' 1=>DIRECT
             1 MEASUREMENT'/' 2=>FOURIER ANALYSIS '///'$INPUT FLAG.   ')
0109   915    FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR SYSTEM RESPONSE
             1(Y OR N)   ')
0110   916    FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR RANGE (Y OR N).  ')
0111   1000   FORMAT(A1)
0112          STOP '****** END OF PROGRAM ******'
```

```
FORTRAN IV      V02.1-1                                          PAGE 004
0113          END
```

```
FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT SPHERE
LOCAL VARIABLES,  PSECT $DATA, SIZE = 000066 (   27. WORDS)

NAME   TYPE  OFFSET      NAME    TYPE  OFFSET      NAME   TYPE  OFFSET

A      L*1   000026      AMPLIT  R*4   000036      FREQ   R*4   000046

INDI   I*2   000052      K       I*2   000034      PHASE  R*4   000042

STEP   R*4   000030
```

```
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:42:40            PAGE 001
0001          SUBROUTINE SYSINP
       C
       C
       C      THIS SUBROUTINE WILL READ IN THE SYSTEM RESPONSE FILES
       C      AND PLACE THEM IN A COMMON BLOCK TO BE PASSED TO OTHER
       C      ROUTINES.
       C
       C
0002          COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
       C
       C
0003          INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512),NPOINT
       C
0004          TYPE 900
0005          TYPE 901
0006          CALL ASSIGN(12,,-1,'OLD','NC',1)
0007          READ(12,*) FSTART
0008          READ(12,*) FEND
0009          READ(12,*) NPOINT
0010          DO 100 K=1,NPOINT
0011          READ(12,*) TRANA(K)
0012          READ(12,*) TRANP(K)
0013   100    CONTINUE
0014          CALL CLOSE(12)
0015          TYPE 902
0016          CALL ASSIGN(12,,-1,'OLD','NC',1)
0017          READ(12,*) FSTART
0018          READ(12,*) FEND
0019          READ(12,*) NPOINT
0020          DO 200 K=1,NPOINT
0021          READ(12,*) CLUTA(K)
0022          READ(12,*) CLUTP(K)
0023   200    CONTINUE
0024          CALL CLOSE(12)
0025          RETURN
0026   900    FORMAT(//1X,'**** SUBROUTINE SYSINP READS THE SYSTEM RESPONSE
             1 FILES ****')
0027   901    FORMAT(//'$','ENTER THE TRANSFER FUNCTION FILE NAME.  ')
0028   902    FORMAT(//'$','ENTER THE ANTENNA SYSTEM FUNCTION FILE NAME   ')
0029          END
```

```
FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT SYSINP
LOCAL VARIABLES,  PSECT $DATA, SIZE = 000020 (    8. WORDS)

NAME   TYPE  OFFSET      NAME   TYPE  OFFSET      NAME   TYPE  OFFSET

K      I*2   000012
```

```
COMMON BLOCK /SYSTA /, SIZE = 010012 ( 2053. WORDS)

NAME   TYPE  OFFSET      NAME   TYPE  OFFSET      NAME   TYPE  OFFSET

TRANA  I*2   000000      TRANP  I*2   002000      CLUTA  I*2   004000

CLUTP  I*2   006000      FSTART R*4   010000      FEND   R*4   010004

NPOINT I*2   010010

LOCAL AND COMMON ARRAYS:

NAME     TYPE   SECTION OFFSET  ------SIZE----- DIMENSIONS
```

```
FORTRAN IV      V02.1-1     THU 09-AUG-79 01:43:34                PAGE 001
0001            SUBROUTINE SPHDAT
         C
         C
         C      THIS SUBROUTINE WILL CALL OBJDAT AND OBTAIN ONE LINE OF
         C      DATA FOR THE SPHERE IF NEW DATA IS SPECIFIED OTHERWISE
         C      AN OLD DATA FILE WILL BE READ.  IN THE CASE OF NEW DATA
         C      THIS ROUTINE WILL WRIE THE NEW FILE WITH THE DESIRED NAME
         C
         C
0002            COMMON/OBJ/OBJA,OBJP,NSAMP2
0003            COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
         C
         C
0004            INTEGER OBJA(512),OBJP(512)
0005            INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512),NPOINT
0006            BYTE A
         C
         C
0007            TYPE 900
0008            TYPE 901
  0009            ACCEPT 700,A
0010            IF(A.EQ.'N') GO TO 300
0012            TYPE 905
0013            ACCEPT *,NSAMP2
0014            TYPE 902
0015            PAUSE
0016            CALL OBJDAT
0017            TYPE 903
0018            CALL ASSIGN(12,,-1,'NEW','NC',1,)
0019            WRITE(12,*) FSTART
0020            WRITE(12,*) FEND
0021            WRITE(12,*) NPOINT
 0022            DO 200 K=1,NPOINT
0023            WRITE(12,*) OBJA(K)
0024            WRITE(12,*) OBJP(K)
0025      200   CONTINUE
0026            CALL CLOSE(12)
0027            GO TO 500
0028      300   TYPE 904
0029            CALL ASSIGN(12,,-1,'OLD','NC',1,)
0030            READ(12,*) FSTART
0031            READ(12,*) FEND
0032            READ(12,*) NPOINT
0033            DO 400 K=1,NPOINT
0034            READ(12,*) OBJA(K)
0035            READ(12,*) OBJP(K)
0036      400   CONTINUE
0037            CALL CLOSE(12)
0038      500   RETURN
0039      700   FORMAT(A1)
0040      900   FORMAT(//1X,'**** SUBROUTINE SPHDAT OBTAINS SWEPT FREQUENCY
               1DATA ****')
0041      901   FORMAT(//'$','TAKE NEW DATA (Y OR N) ?')
0042      902   FORMAT(//1X,'SET UP THE SPHERE, HIT RETURN TO CONTINUE')

FORTRAN IV      V02.1-1     THU 09-AUG-79 01:43:34                PAGE 002
0043      903   FORMAT(//'$','ENTER NEW SPHERE DATA FILE NAME: ')
0044      904   FORMAT(//'$','ENTER OLD SPHERE DATA FILE NAME: ')
0045      905   FORMAT(//'$','ENTER NUMBER OF MEASURMENTS AT EACH FREQUENCY
               1 POINT: ')
0046            END
```

```
FORTRAN IV     STORAGE MAP FOR PROGRAM UNIT SPHDAT
   LOCAL VARIABLES, .PSECT $DATA, SIZE = 000022 (     9. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

A      L*1   000012     K      I*2   000014


COMMON BLOCK /OBJ   /, SIZE = 004002 ( 1025. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

OBJA   I*2   000000     OBJP   I*2   002000     NSAMP2 I*2   004000

COMMON BLOCK /SYSTA /, SIZE = 010012 ( 2053. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET

TRANA  I*2   000000     TRANP  I*2   002000     CLUTA  I*2   004000

CLUTP  I*2   006000     FSTART R*4   010000     FEND   R*4   010004

NPOINT I*2   010010

LOCAL AND COMMON ARRAYS:

NAME      TYPE    SECTION OFFSET   ------SIZE----- DIMENSIONS
CLUTA  I*2        SYSTA   004000   002000 (   512.) (512)
CLUTP  I*2        SYSTA   006000   002000 (   512.) (512)
OBJA   I*2        OBJ     000000   002000 (   512.) (512)
OBJP   I*2        OBJ     002000   002000 (   512.) (512)
TRANA  I*2        SYSTA   000000   002000 (   512.) (512)
TRANP  I*2        SYSTA   002000   002000 (   512.) (512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE

ASSIGN R*4    CLOSE  R*4    OBJDAT R*4
```

```
FORTRAN IV      V02 1-1      SUN 19-AUG-79 01:46:41                    PAGE 001
0001            SUBROUTINE OBJDAT
          C
          C
          C     THIS SUBROUTINE WILL OBTAIN DATA FOR AN OBJECT OVER THE FREQ
          C     RANGE SET WITH THE NUMBER OF POINTS SPECIFIED.
          C
          C
          C
0002            COMMON/OBJ/OBJA,OBJP,NSAMP2
0003            COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
          C
          C
0004            INTEGER OBJA(512),OBJP(512),NPOINT
0005            INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512)
          C
0006            STEP=(FEND-FSTART)/FLOAT(NPOINT)
0007            CALL SWEEP(1,FSTART,1,4)
0008            DO 100 K=1,NPOINT
0009            FREQ=FSTART+FLOAT(K-1)*STEP
0010            CALL SWEEP(1,FREQ,1,4)
0011            CALL PHAMP2(IA,IP,NSAMP2)
0012            OBJA(K)=IA-2048
0013            OBJP(K)=IP-2048
0014      100   CONTINUE
0015            CALL SWEEP(1,FSTART,1,4)
0016            RETURN
0017            END

FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT OBJDAT
LOCAL VARIABLES,  PSECT $DATA,  SIZE = 000026 (    11.  WORDS)

NAME    TYPE  OFFSET      NAME    TYPE  OFFSET      NAME    TYPE  OFFSET

FREQ    R*4   000014      IA      I*2   000020      IP      I*2   000022

K       I*2   000012      STEP    R*4   000006


COMMON BLOCK /OBJ   /,  SIZE = 004002 ( 1025  WORDS)

NAME    TYPE  OFFSET      NAME    TYPE  OFFSET      NAME    TYPE  OFFSET

OBJA    I*2   000000      OBJP    I*2   002000      NSAMP2 I*2    004000

COMMON BLOCK /SYSTA /,  SIZE = 010012 ( 2053. WORDS)

NAME    TYPE  OFFSET      NAME    TYPE  OFFSET      NAME    TYPE  OFFSET

TRANA   I*2   000000      TRANP   I*2   002000      CLUTA   I*2   004000

CLUTP   I*2   006000      FSTART R*4    010000      FEND    R*4   010004

NPOINT  I*2   010010

LOCAL AND COMMON ARRAYS:

NAME      TYPE    SECTION OFFSET  ------SIZE-----  DIMENSIONS
CLUTA     I*2     SYSTA   004000  002000 (  512.)  (512)
CLUTP     I*2     SYSTA   006000  002000 (  512.)  (512)
OBJA      I*2     OBJ     000000  002000 (  512.)  (512)
```

```
FORTRAN IV      V02.1-1      SUN 07-OCT-79 00:11:12                    PAGE 001
0001            SUBROUTINE CORREC
          C
          C     THIS SUBROUTINE WILL TAKE THE DATA THAT WAS TAKEN FROM
          C     SPHDAT AND CORRECT IT WITH THE DATA FROM SUBROUTINE
          C     SYSINP, WHICH IS THE SYSTEM RESPONSE.
          C
          C     VERSION 1.1 7-OCT-79
          C
0002            COMMON/OBJ/OBJA,OBJP,NSAMP2
0003            COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
          C
          C
0004            INTEGER OBJA(512),OBJP(512),TRANA(512),TRANP(512)
0005            INTEGER CLUTA(512),CLUTP(512),NPOINT,NSAMP2
          C
          C     ***************************************************************
          C     SUBTRACT ANTENNA CLUTTER FROM OBJECT DATA. THIS CLUTTER DATA
          C     MUST NOT!!! BE CORRECTED FOR THE SYSTEM TRANSFER FUCTION
          C
          C     THE NEXT STEP IS TO DIVIDE BY THE TRANSFER CHARACTERISTIC
          C     OF THE SYSTEM IN ARRAYS TRANA(AMPLITUDE) AND TRANP(PHASE).
          C
          C     ***************************************************************
          C
0006            PI=3.1415926
0007            DEG=PI/180
0008            DO 100 K=1,NPOINT

   0009            CDBAMP=FLOAT(CLUTA(K))*.05
0010            CLPH=FLOAT(CLUTP(K))*.25*DEG
0011            TDBAMP=FLOAT(TRANA(K))*.05
0012            TRPH=FLOAT(TRANP(K))*.25*DEG
0013            ODBAMP=FLOAT(OBJA(K))*.05
0014            OBJPH=FLOAT(OBJP(K))*.25*DEG
          C
          C     ***************************************************************
          C     CDBAMP=>CLUTTER IN DBM
          C     CLPH=>CLUTTER PHASE IN RADIANS
          C     TDBAMP=>TRANSFER CHARACTERISTIC IN DBM
          C     TRPH=>PHASE OF TRANSFER CHARACTERISTIC IN RADIANS
          C     ODBAMP=>OBJECT AMPLITUDE IN DBM.
          C     OBJPH=>PHASE OF OBJECT DATA IN RADIANS
          C     OBJAMP=>OBJECT AMPLITUDE IN MILLIWATTS
          C     CLAMP=>CLUTTER AMPLITUDE IN MILLIWATTS
          C     ***************************************************************
          C
0015            CLAMP=10.**(CDBAMP/10.)
0016            OBJAMP=10.**(ODBAMP/10.)
          C
          C     ***************************************************************
          C     CLCOS=>REAL PART OF CLUTTER
          C     CLSIN=>IMAGINARY PART OF CLUTTER
          C     OBJCOS=>REAL PART OBJECT DATA
          C     OBJSIN=>IMAGINARY PART OF OBJECT DATA
          C     ***************************************************************
FORTRAN IV      V02.1-1      SUN 07-OCT-79 00:11:12                    PAGE 002
          C
0017            OBJCOS=OBJAMP*COS(OBJPH)
0018            OBJSIN=OBJAMP*SIN(OBJPH)
0019            CLCOS=CLAMP*COS(CLPH)
```

```
      CLSIN=CLAMP*SIN(CLPH)
C
C     ***********************************************************
C      TEMCOS=>REAL PART OF OBJECT-CLUTTER
C      TEMSIN=>IMAGINARY PART OF OBJECT-CLUTTER
C      ATEMP=>MAGNITUDE OF OBJECT-CLUTTER
C      ADBTEM=>MAGNITUDE IN DBM OF (OBJECT-CLUTTER)
C      PTEMP=>PHASE OF OBJECT-CLUTTER
C      ADBRES=>MAGNITUDE OF RESULT(ATEMP/TRAMP) DIVIDE BY TRANSFER
C         CHARACTERISTIC IN DBM
C      PRES=>PHASE OF RESULT((OBJECT-CLUTTER)/TRANSFER)
C     ***********************************************************
C
C     ********** SUBTRACT CLUTTER FROM OBJECT DATA ****************
C
      TEMCOS=OBJCOS-CLCOS
      TEMSIN=OBJSIN-CLSIN
C
C     ********* CONVERT BACK TO PHASOR FORM **********************
C
      PTEMP=ATAN2(TEMSIN,TEMCOS)
C
         ATEMP=SQRT(TEMSIN**2+TEMCOS**2)
C
C     ********* DIVIDE BY TRANSFER CHARACTERISTIC ****************
C
      ADBTEM=10.*ALOG10(ATEMP)
      ADBRES=ADBTEM-TDBAMP
      PRES=(PTEMP-TRPH)
      IF(PRES.GT.PI)PRES=PRES-2.*PI
      IF(PRES.LT.-PI)PRES=PRES+2.*PI
C
C     ********* REPLACE DATA INTO INTEGER ARRAY ******************
C
      OBJA(K)=IFIX(20.*ADBRES)
      OBJP(K)=IFIX((PRES/DEG)*4.)
 100  CONTINUE
      RETURN
      END
```

FORTRAN IV   STORAGE MAP FOR PROGRAM UNIT CORREC
LOCAL VARIABLES. PSECT $DATA, SIZE = 000162 (57. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
ADBRES	R*4	000134	ADBTEM	R*4	000130	ATEMP	R*4	000124
CDBAMP	R*4	000030	CLAMP	R*4	000060	CLCOS	R*4	000100
CLPH	R*4	000034	CLSIN	R*4	000104	DEG	R*4	000022
K	I*2	000026	OBJAMP	R*4	000064	OBJCOS	R*4	000070
OBJPH	R*4	000054	OBJSIN	R*4	000074	ODBAMP	R*4	000050
PI	R*4	000016	PRES	R*4	000140	PTEMP	R*4	000120
TDBAMP	R*4	000040	TEMCOS	R*4	000110	TEMSIN	R*4	000114
TRPH	R*4	000044						


```
      SUBROUTINE RANGE
C
C     VERSION 1.1
C
C     THIS SUBROUTINE WILL CALCULATE THE DISTANCE TO THE OBJECT
C     AND RETURN THAT VALUE. DEPENDING ON THE FLAG PASSED IT WILL
C     QUERY WHAT TECHNIQUE TO BE USED IN THE RANGE CALCULATION
C
C
         COMMON /RANGE1/DIST,IRFLAG,IUNIT
      COMMON /OBJ/OBJA,OBJP,NSAMP2
      COMMON /SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
C
C
      INTEGER OBJA(512),OBJP(512),TRANA(512),TRANP(512)
      INTEGER CLUTA(512),CLUTP(512),NPOINT,NSAMP2,IRFLAG
      REAL PWR(512),C,PI
      DATA C/2.997925E+08/,PI/3.1415926/
C
 100  IF (IRFLAG.NE.1) GO TO 200
C    ****** THIS SECTION FOR DIRECT RANGE INPUT ********************
C
      TYPE 900
      ACCEPT *,DIST
      GO TO 1000
 200  IF (IRFLAG.NE.2) GO TO 1000
C    ****** THIS SECTION FOR FOURIER TRANSFORM METHOD FOR RANGE *****
C
      AMULT=ALOG(FLOAT(NPOINT))/ALOG(2.)
      IF (ABS(AMULT-IFIX(AMULT))-.001) 300,300,400
 300  N=2.**IFIX(AMULT+.01)
      GO TO 500
 400  N=2.**(IFIX(AMULT)+1)
 500  TYPE *,'THE NUMBER OF POINTS IN TRANSFORM: ',N
C
C    ***** ZERO OUT CLUTA AND CLUTP ARRAYS FOR LATER USE ************
C
      DO 510 K=1,512
      CLUTA(K)=0
      CLUTP(K)=0
 510  CONTINUE
C
C    ***** FIND SCALE FACTOR ****************************************
C
      AMX=0
      DO 550 K=1,NPOINT
      AMP=10.**(FLOAT(OBJA(K)*.05)/10.)
      AMX=AMX+AMP
 550  CONTINUE
      AMX=6.*(AMX/FLOAT(NPOINT))
      SCALE=32676./AMX
      TYPE *,'   '
      TYPE *,'SCALE FACTOR: ',SCALE
      DO 600 K=1,NPOINT
```



```
      PHASE=FLOAT(OBJP(K))*.25*PI/180.
      AMDB=FLOAT(OBJA(K))*.05
```

```
      AM=SCALE*10 **(AMDB/10.)
      AMR=AM*COS(PHASE)
      AMI=AM*SIN(PHASE)
      IF(ABS(AMR) GE 32676) AMR=SIGN(32676.,AMR)
      IF(ABS(AMI) GE 32676) AMI=SIGN(32676.,AMI)
C
C     ******* REUSE CLUTA AND CLUTP ARRAYS FOR FOURIER TRANSFORM ****
C
      CLUTA(K)=IFIX(AMR)
      CLUTP(K)=IFIX(AMI)
 600  CONTINUE
      CALL FFT(IERROR,N,CLUTA,CLUTP,1,ISCALE)
      CALL POWRSP(N,CLUTA,CLUTP,PWR)
      ALIAS=C/(4 *((FEND-FSTART)/FLOAT(N))*1.E9)
      RES=C/((FEND-FSTART)*2 *1.E9)
      WRITE(IUNIT,901)ALIAS,RES
C
C     ***** FIND MAXIMUM ENERGY POINT AND RANGE *********************
C
      AMPMAX=0
      DO 800 K=1,(N/2)
      IF (AMPMAX-PWR(K)) 750,750,800
 750  AMPMAX=PWR(K)
      KMAX=K
 800  CONTINUE
      DIST=KMAX*RES
 1000 RETURN
 900  FORMAT(////'$ENTER THE DISTANCE TO THE OBJECT IN METERS. ')
 901  FORMAT(///////' ALIASING RANGE (METERS):   ',1PG15.7
     1//' RESOLUTION (METERS):  ',1PG15.7)
      END
```

FORTRAN IV   STORAGE MAP FOR PROGRAM UNIT RANGE

LOCAL VARIABLES, .PSECT $DATA, SIZE = 004156 (1079. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
ALIAS	R*4	004104	AM	R*4	004064	AMDB	R*4	004060
AMI	R*4	004074	AMP	R*4	004044	AMPMAX	R*4	004114
AMR	R*4	004070	AMULT	R*4	004030	AMX	R*4	004040
C	R*4	004000	IERROR	I*2	004100	ISCALE	I*2	004102
K	I*2	004036	KMAX	I*2	004120	N	I*2	004034
PHASE	R*4	004054	PI	R*4	004004	RES	R*4	004110
SCALE	R*4	004050						

COMMON BLOCK /RANGE1/, SIZE = 000010 (4. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
DIST	R*4	000000	IRFLAG	I*2	000004	IUNIT	I*2	000006

COMMON BLOCK /OBJ /, SIZE = 004002 (1025. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET


```
      SUBROUTINE RANCOR
C
C     VERSION 1.3 7-OCT-79
C
C     THIS SUBROUTINE WILL CORRECT THE OBJECT DATE FOR RANGE
C
C
      COMMON/RANGE1/DIST,IRFLAG,IUNIT
      COMMON/OBJ/OBJA,OBJP,NSAMP2
      COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
C
C
      INTEGER IRFLAG,OBJA(512),OBJP(512),NSAMP2,TRANA(512)
      INTEGER TRANP(512),CLUTA(512),CLUTP(512),NPOINT
      REAL*4  DIST,FSTART,FEND,PATH,KSTART,KFREQ,PI,C,KDELTA
      DATA PI/3.1415926/,C/2.997925E+08/
C
C
      PATH=2.*DIST
      KSTART=2 *PI*(FSTART*1.E+09)/C
      FDELTA=(FEND-FSTART)/FLOAT(NPOINT)
      KDELTA=2 *PI*(FDELTA*1.E+09)/C
      KFREQ=KSTART
      TWOPI=2 *PI
      RAD=PI/180
      DEG=180 /PI
      DO 100  K=1,NPOINT
      PHASE=-(PATH*KFREQ)
      PHADAT=FLOAT(OBJP(K))*.25*RAD
      PHNEW=PHADAT-PHASE
      PHNEW=AMOD(PHNEW,TWOPI)
      IF (PHNEW GT PI) PHNEW=PHNEW-TWOPI
      IF (PHNEW LT -PI) PHNEW=PHNEW+TWOPI
      OBJP(K)=IFIX(PHNEW*DEG*4.)
      KFREQ=KFREQ+KDELTA
 100  CONTINUE
      RETURN
      END
```

FORTRAN IV   STORAGE MAP FOR PROGRAM UNIT RANCOR

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000104 (34. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
C	R*4	000006	DEG	R*4	000050	FDELTA	R*4	000034
K	I*2	000054	KDELTA	R*4	000030	KFREQ	R*4	000024
KSTART	R*4	000020	PATH	R*4	000014	PHADAT	R*4	000062
PHASE	R*4	000056	PHNEW	R*4	000066	PI	R*4	000002
RAD	R*4	000044	TWOPI	R*4	000040			

COMMON BLOCK /RANGE1/, SIZE = 000010 (4. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET

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```
      PROGRAM SPHER2
C
C     VERSION 1.0 30-NOV-79
C
C     THIS PROGRAM WILL TAKE EXPERIMENTAL DATA FOR THE SPHERE
C     AND CORRECT IT FOR THE SYSTEM RESPONSE. IT WILL PRINT
C     BOTH THE CORRECTED AND UNCORRECTED DATA AND FINNALY DISPLAY
C     IT ON THE HIGH RESOLUTION CRT
C
C     ALSO IT DESIRED IT WILL GENERATE IF DESIRED ANALYITICAL
C     DATA FOR THE SPHERE AND STORE IT IN A FILE. IT WILL ALSO
C     PRINT THIS DATA IF DESIRED TO A FILE AND ALSO DISPLAY IT ON
C     THE HIGH RESOLUTION CRT MONITOR
C
C
      COMMON/RANGE1/DIST,IRFLAG,IUNIT
      COMMON/OBJ/OBJA,OBJP,NSAMP2
      COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
C
C
      INTEGER OBJA(512),OBJP(512),TRANA(512)
      INTEGER TRANP(512),CLUTA(512),CLUTP(512),NPOINT,NSAMP2
      BYTE A
C
C
      TYPE 900
      TYPE 912
      ACCEPT *,IUNIT
C
C     THIS SECTION WILL GENERATE CORRECTED SPHERE DATA FROM
C     EXPERIMENTAL DATA
C
      TYPE 902
      CALL SYS1
      STEP=(FEND-FSTART)/FLOAT(NPOINT)
      TYPE *,'PRINT THE SYSTEM REPONSE DATA (Y OR N)'
      ACCEPT 1000,A
      IF (A.EQ.'N') GO TO 100
      WRITE(IUNIT,917)
      WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
      WRITE(IUNIT,906)
      DO 20 K=1,NPOINT
      AMPLIT=FLOAT(TRANA(K))*.05
      PHASE=FLOAT(TRANP(K))*.25
      FREQ=FSTART+FLOAT(K-1)*STEP
      WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
   20 CONTINUE
      WRITE(IUNIT,918)
      WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
      WRITE(IUNIT,906)
      DO 30 K=1,NPOINT
      AMPLIT=FLOAT(CLUTA(K))*.05
      FREQ=FSTART+FLOAT(K-1)*STEP
      PHASE=FLOAT(CLUTP(K))*.25

      WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
   30 CONTINUE
  100 CALL SPHDAT
      CALL SWEEP(10,...)
      TYPE 903
      ACCEPT 1000,A
      IF (A.EQ.'N') GO TO 220
      WRITE(IUNIT,904)
      WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
      WRITE(IUNIT,906)
      DO 210 K=1,NPOINT
      AMPLIT=FLOAT(OBJA(K))*.05
      PHASE=FLOAT(OBJP(K))*.25
      FREQ=FSTART+FLOAT(K-1)*STEP
      WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
  210 CONTINUE
  220 CALL CORREC
C
C     HERE LIST THE CORRECTED SPHERE DATA
C
  250 TYPE 915
      ACCEPT 1000,A
      IF (A.EQ.'N') GO TO 280
      WRITE(IUNIT,909)
      WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
      WRITE(IUNIT,906)
      DO 277 K=1,NPOINT
      IND1=K
      AMPLIT=FLOAT(OBJA(K))*.05
      PHASE=FLOAT(OBJP(K))*.25
      FREQ=FSTART+FLOAT(IND1-1)*STEP
      WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
  277 CONTINUE
  280 CONTINUE
C
C     THIS SECTION WILL STORE THE CORRECTED DATA FOR SYSTEM RESPONSE
C
      TYPE 802
      ACCEPT 1000,A
      IF (A.EQ.'N') GO TO 400
      TYPE 801
      CALL ASSIGN(20,,-1,'NEW','NC',)
      WRITE(20,*)FSTART
      WRITE(20,*)FEND
      WRITE(20,*)NPOINT
      DO 310 K=1,NPOINT
      WRITE(20,*)OBJA(K)
      WRITE(20,*)OBJP(K)
  310 CONTINUE
      CALL CLOSE(20)
C
C     THIS SECTION WILL CORRECT FOR RANGE
C
  400 TYPE 914

      ACCEPT *,IRFLAG
      CALL RANGE
C
      TYPE 913,DIST
      CALL RANCOR
      TYPE 916
      ACCEPT 1000,A
      IF (A.EQ.'N') GO TO 470
      WRITE(IUNIT,913)DIST
      WRITE(IUNIT,911)
      WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
```

```
      WRITE(IUNIT,906)
      DO 410 K=1,NPOINT
      IND1=K
      AMPLIT=FLOAT(OBJA(K))*.05
      PHASE=FLOAT(OBJP(K))*.25
      FREQ=FSTART+FLOAT(IND1-1)*STEP
      WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
410   CONTINUE
C
C     THIS SECTION WILL STORE THE RANGE CORRECTED DATA
C
C
470   TYPE 901
      ACCEPT 1000,A
      IF (A EQ 'N') GO TO 500
      TYPE 800
      CALL ASSIGN(20,,-1,'NEW','NC',)
      WRITE(20,*)FSTART
      WRITE(20,*)FEND
      WRITE(20,*)NPOINT
      DO 460 K=1,NPOINT
      WRITE(20,*)OBJA(K)
      WRITE(20,*)OBJP(K)
460   CONTINUE
      CALL CLOSE(20)
C
C     THIS SECTION WILL DISPLAY THE DATA
C
500   CONTINUE
C
C     FORMAT STATEMENTS
C
800   FORMAT(///,'$ENTER THE FILE NAME FOR THE RANGE
     1CORRECTED DATA: ')
801   FORMAT(///,'$ENTER THE FILE NAME FOR THE COORECTED DATA: ')
802   FORMAT(///,'$DO YOU WANT TO STORE THE CORRECTED DATA (Y OR N)
     1  ')
900   FORMAT(////,'**** PROGRAM SPHERE ****')
901   FORMAT(///,'$DO YOU WANT TO STORE THE RANGE CORRECTED
     1DATA (Y OR N) ? ')
902   FORMAT(//,' THIS SECTION WILL GENERATE CORRECTED SPHERE DATA
     1FROM '/' EXPERIMENTAL DATA')
903   FORMAT(//,'$PRINT THE UNCORRECTED DATA (Y OR N):  ')
904   FORMAT(///////,'***** UNCORRECTED SPHERE DATA *****')
905   FORMAT(/15X,'STARTING FREQUENCY GHZ:   ',1PG15.7/15X,
     1'ENDING FREQUENCY IN GHZ:  ',1PG15.7/15X,'FREQUENCY STEP GHZ:
     2,1PG15.7/15X,'NUMBER OF STEPS:    ',I7)
906   FORMAT(//1X,75('*')/12X,'POINT #',5X,'FREQUENCY',7X,
     1'AMPLITUDE DB  ',5X,'PHASE DEGREES'/1X,75('*')/)
907   FORMAT(10X,I7,5X,1PG15.7,3X,1PG15.7,3X,1PG15.7)
909   FORMAT(///////,' ***** CORRECTED EXPERIMENTAL SPHERE
     1DATA *****')
911   FORMAT(///////,' ***** EXPERIMENTAL SPHERE DATA CORRECTED
     1FOR RANGE *****')
912   FORMAT(////'$','ENTER LOGICAL UNIT NUMBER FOR OUTPUT (7=>
     1TERMINAL)  ')
913   FORMAT(////,' CALCULATED RANGE TO THE TARGET= ',1PG15.7,
     1' METERS')
914   FORMAT(///,' ENTER THE RANGE CALCULATION FLAG'///' 1=>DIRECT
     1 MEASUREMENT'/' 2=>FOURIER ANALYSIS '///'$INPUT FLAG.  ')
915   FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR SYSTEM RESPONSE
     1(Y OR N):  ')
916   FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR RANGE (Y OR N).  ')
917   FORMAT(///////,' ******** TRANSFER CHARACTERISTIC OF SYSTEM **
     1******')
918   FORMAT(///////,' ******** SYSTEM CLUTTER *********')
1000  FORMAT(A1)
      STOP '****** END OF PROGRAM ******'
      END
```

LOCAL VARIABLES, PSECT $DATA, SIZE = 000102 (33. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
A	L*1	000036	AMPLIT	R*4	000046	FREQ	R*4	000056
IND1	I*2	000062	K	I*2	000044	PHASE	R*4	000052
STEP	R*4	000040						

COMMON BLOCK /RANGE1/, SIZE = 000010 (4. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
DIST	R*4	000000	IRFLAG	I*2	000004	IUNIT	I*2	000006

COMMON BLOCK /OBJ   /, SIZE = 004002 (1025 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
OBJA	I*2	000000	OBJP	I*2	002000	NSAMP2	I*2	004000

COMMON BLOCK /SYSTA /, SIZE = 010012 (2053 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
TRANA	I*2	000000	TRANP	I*2	002000	CLUTA	I*2	004000
CLUTP	I*2	006000	FSTART	R*4	010000	FEND	R*4	010004
NPOINT	I*2	010010						

LOCAL AND COMMON ARRAYS

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
CLUTA	I*2	SYSTA	004000	002000 (512)	(512)
CLUTP	I*2	SYSTA	006000	002000 (512)	(512)
OBJA	I*2	OBJ	000000	002000 (512)	(512)
OBJP	I*2	OBJ	002000	002000 (512)	(512)
TRANA	I*2	SYSTA	000000	002000 (512)	(512)
TRANP	I*2	SYSTA	002000	002000 (512)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	CLOSE	R*4	CORREC	R*4	FLOAT	R*4	RANCOR	R*4
RANGE	R*4	SPHDAT	R*4	SWEEP	R*4	SYS1	R*4		

```
      SUBROUTINE SYS1
C     VERSION 1.0 29-NOV-79
C
C
C     THIS SUBROUTINE WILL READ IN THE SYSTEM RESPONSE FILES
C     AND PLACE THEM IN A COMMON BLOCK TO BE PASSED TO OTHER
C     ROUTINES
C
C
      COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
C
      BYTE C
      INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512),NPOINT
C
      TYPE 900
      TYPE *,'OLD OR NEW DATA (1=>NEW,0=>OLD)'
      ACCEPT *,FLAG
      IF (FLAG) 50,50,10
10    TYPE *, 'ENTER THE STARTING FREQ IN GHZ:'
      ACCEPT *,FSTART
      TYPE *,'ENTER THE ENDING FREQ IN GHZ:'
      ACCEPT *,FEND
      TYPE *,'ENTER THE NUMBER OF FREQ  POINTS:'
      ACCEPT *,NPOINT
      TYPE *,'ENTER THE NUMBER OF SAMPLES AT EACH FREQ.:'
      ACCEPT *,NSAMP2
      TYPE *,'SET UP REFLECTING PLANE FOR TRANSFER FUNCTION MEASURMENT'
      PAUSE '***** HIT RETURN TO PROCEED *****'
      CALL SWDAT(TRANA,TRANP,FSTART,FEND,NPOINT,NSAMP2)
      TYPE *,'SET UP FOR CLUTTER MEASUREMENT'
      PAUSE '***** HIT RETURN TO PROCEED *****'
      CALL SWDAT(CLUTA,CLUTP,FSTART,FEND,NPOINT,NSAMP2)
      TYPE *,'STORE DATA ON DISC? (Y OR N)'
      ACCEPT 800,C
      IF (C.EQ.'N') GOTO 300
      TYPE 901
      CALL ASSIGN(12,,-1,'NEW','NC',1,)
      WRITE(12,*) FSTART
      WRITE(12,*) FEND
      WRITE(12,*) NPOINT
      DO 30 K=1,NPOINT
      WRITE(12,*) TRANA(K)
      WRITE(12,*) TRANP(K)
30    CONTINUE
      CALL CLOSE(12)
      TYPE 902
      CALL ASSIGN(12,,-1,'NEW','NC',1,)
      WRITE(12,*) FSTART
      WRITE(12,*) FEND
      WRITE(12,*) NPOINT
      DO 40 K=1,NPOINT
      WRITE(12,*) CLUTA(K)
      WRITE(12,*) CLUTP(K)
40    CONTINUE

      CALL CLOSE(12)
      GO TO 300
50    TYPE 901
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      DO 100 K=1,NPOINT
      READ(12,*) TRANA(K)
      READ(12,*) TRANP(K)
100   CONTINUE
      CALL CLOSE(12)
      TYPE 902
      CALL ASSIGN(12,,-1,'OLD','NC',1)
      READ(12,*) FSTART
      READ(12,*) FEND
      READ(12,*) NPOINT
      DO 200 K=1,NPOINT
      READ(12,*) CLUTA(K)
      READ(12,*) CLUTP(K)
200   CONTINUE
      CALL CLOSE(12)
300   RETURN
800   FORMAT (A1)
900   FORMAT(//1X,'**** SUBROUTINE SYSINP OBTAINS THE SYSTEM RESPONSE
     1 FILES ****')
901   FORMAT(//'$','ENTER THE TRANSFER FUNCTION FILE NAME: ')
902   FORMAT(//'$','ENTER THE ANTENNA SYSTEM FUNCTION FILE NAME: ')
      END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000044 (18. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
C	L*1	000022	FLAG	R*4	000024	K	I*2	000032
NSAMP2	I*2	000030						

COMMON BLOCK /SYSTA /, SIZE = 010012 (2053. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
TRANA	I*2	000000	TRANP	I*2	002000	CLUTA	I*2	004000
CLUTP	I*2	006000	FSTART	R*4	010000	FEND	R*4	010004
NPOINT	I*2	010010						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
CLUTA	I*2	SYSTA	004000	002000 (512.)	(512)
CLUTP	I*2	SYSTA	006000	002000 (512.)	(512)
TRANA	I*2	SYSTA	000000	002000 (512.)	(512)
TRANP	I*2	SYSTA	002000	002000 (512.)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	CLOSE	R*4	SWDAT	R*4				

```
FORTRAN IV V02 1-1    FRI 30-NOV-79 00:25:58       PAGE 001
0001           PROGRAM SPHER3
         C
         C     VERSION 1.0 30-NOV-79
         C
         C     THIS PROGRAM WILL TAKE EXPERIMENTAL DATA FOR THE SPHERE
         C     AND CORRECT IT FOR THE SYSTEM RESPONSE. IT WILL PRINT
         C     BOTH THE CORRECTED AND UNCORRECTED DATA AND FINNALY DISPLAY
         C     IT ON THE HIGH RESOLUTION CRT.
         C
         C     ALSO IT DESIRED IT WILL GENERATE IF DESIRED ANALYITICAL
         C     DATA FOR THE SPHERE AND STORE IT IN A FILE. IT WILL ALSO
         C     PRINT THIS DATA IF DESIRED TO A FILE AND ALSO DISPLAY IT ON
         C     THE HIGH RESOLUTION CRT MONITOR.
         C
         C
0002           COMMON/RANGE1/DIST,IRFLAG,IUNIT
0003           COMMON/OBJ/OBJA,OBJP,NSAMP2
0004           COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
         C
         C
0005           INTEGER OBJA(512),OBJP(512),TRANA(512)
0006           INTEGER TRANP(512),CLUTA(512),CLUTP(512),NPOINT,NSAMP2
0007           BYTE A
         C
         C
0008           TYPE 900
0009           TYPE 912
0010           ACCEPT *,IUNIT
         C
         C     THIS SECTION WILL GENERATE CORRECTED SPHERE DATA FROM
         C     EXPERIMENTAL DATA
         C
0011           TYPE 902
0012           CALL SYS2
0013           STEP=(FEND-FSTART)/FLOAT(NPOINT)
0014           TYPE *,'PRINT THE SYSTEM REPONSE DATA (Y OR N)'
0015           ACCEPT 1000,A
0016           IF (A.EQ.'N') GO TO 100
0018           WRITE(IUNIT,917)
0019           WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0020           WRITE(IUNIT,906)
0021           DO 20 K=1,NPOINT
0022           AMPLIT=FLOAT(TRANA(K))*.05
0023           PHASE=FLOAT(TRANP(K))*.25
0024           FREQ=FSTART+FLOAT(K-1)*STEP
0025           WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0026     20    CONTINUE
0027    100    CALL SPHDAT
0028           CALL SWEEP(10,...,)
0029           TYPE 903
0030           ACCEPT 1000,A
0031           IF (A.EQ.'N') GO TO 220
0033           WRITE(IUNIT,904)
0034           WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT

0035           WRITE(IUNIT,906)
0036           DO 210 K=1,NPOINT
0037           AMPLIT=FLOAT(OBJA(K))*.05
0038           PHASE=FLOAT(OBJP(K))*.25
0039           FREQ=FSTART+FLOAT(K-1)*STEP
0040           WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0041    210    CONTINUE
0042    220    CALL CORDAT
         C
         C     HERE LIST THE CORRECTED SPHERE DATA
         C
0043    250    TYPE 915
0044           ACCEPT 1000,A
0045           IF (A.EQ.'N') GO TO 280
0047           WRITE(IUNIT,909)
0048           WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0049           WRITE(IUNIT,906)
0050           DO 277 K=1,NPOINT
0051           IND1=K
0052           AMPLIT=FLOAT(OBJA(K))*.05
0053           PHASE=FLOAT(OBJP(K))*.25
0054           FREQ=FSTART+FLOAT(IND1-1)*STEP
0055           WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
0056    277    CONTINUE
0057    280    CONTINUE
         C
         C     THIS SECTION WILL STORE THE CORRECTED DATA FOR SYSTEM RESPONSE
         C
0058           TYPE 802
0059           ACCEPT 1000,A
0060           IF (A.EQ.'N') GO TO 400
0062           TYPE 801
0063           CALL ASSIGN(20,,-1,'NEW','NC',)
0064           WRITE(20,*)FSTART
0065           WRITE(20,*)FEND
0066           WRITE(20,*)NPOINT
0067           DO 310 K=1,NPOINT
0068           WRITE(20,*)OBJA(K)
0069           WRITE(20,*)OBJP(K)
0070    310    CONTINUE
0071           CALL CLOSE(20)
         C
         C     THIS SECTION WILL CORRECT FOR RANGE
         C
0072    400    TYPE 914
0073           ACCEPT *,IRFLAG
0074           CALL RANGE
         C
0075           TYPE 913,DIST
0076           CALL RANCOR
0077           TYPE 916
0078           ACCEPT 1000,A
0079           IF (A.EQ.'N') GO TO 470
0081           WRITE(IUNIT,913)DIST

0082           WRITE(IUNIT,911)
0083           WRITE(IUNIT,905)FSTART,FEND,STEP,NPOINT
0084           WRITE(IUNIT,906)
0085           DO 410 K=1,NPOINT
0086           IND1=K
0087           AMPLIT=FLOAT(OBJA(K))*.05
0088           PHASE=FLOAT(OBJP(K))*.25
0089           FREQ=FSTART+FLOAT(IND1-1)*STEP
```

```
          WRITE(IUNIT,907)K,FREQ,AMPLIT,PHASE
  410     CONTINUE
C
C         THIS SECTION WILL STORE THE RANGE CORRECTED DATA
C
C
  470     TYPE 901
          ACCEPT 1000,A
          IF (A EQ 'N') GO TO 500
          TYPE 800
          CALL ASSIGN(20,,-1,'NEW','NC',)
          WRITE(20,*)FSTART
          WRITE(20,*)FEND
          WRITE(20,*)NPOINT
          DO 460 K=1,NPOINT
          WRITE(20,*)OBJA(K)
          WRITE(20,*)OBJP(K)
  460     CONTINUE
          CALL CLOSE(20)
C
C         THIS SECTION WILL DISPLAY THE DATA
C
  500     CONTINUE
C
C         FORMAT STATEMENTS
C
  800     FORMAT(///,'$ENTER THE FILE NAME FOR THE RANGE
         1CORRECTED DATA  ')
  801     FORMAT(///,'$ENTER THE FILE NAME FOR THE COORECTED DATA. ')
  802     FORMAT(///,'$DO YOU WANT TO STORE THE CORRECTED DATA (Y OR N)
         1   ')
  900     FORMAT(////,'**** PROGRAM SPHERE ****')
  901     FORMAT(///,'$DO YOU WANT TO STORE THE RANGE CORRECTED
         1DATA (Y OR N) ? ')
  902     FORMAT(//,' THIS SECTION WILL GENERATE CORRECTED SPHERE DATA
         1FROM '/' EXPERIMENTAL DATA')
  903     FORMAT(//,'$PRINT THE UNCORRECTED DATA (Y OR N):  ')
  904     FORMAT(///////,'***** UNCORRECTED SPHERE DATA *****')
  905     FORMAT(/15X,'STARTING FREQUENCY GHZ:  ',1PG15.7/15X,
         1'ENDING FREQUENCY IN GHZ:  ',1PG15.7/15X,'FREQUENCY STEP GHZ:
         2,1PG15.7/15X,'NUMBER OF STEPS:  ',I7)
  906     FORMAT(//1X,75('*')/12X,'POINT #',5X,'FREQUENCY',7X,
         1'AMPLITUDE DB  ',5X,'PHASE DEGREES'/1X,75('*')/)
  907     FORMAT(10X,I7,5X,1PG15.7,3X,1PG15.7,3X,1PG15.7)
  909     FORMAT(///////,' ***** CORRECTED EXPERIMENTAL SPHERE
         1DATA *****')
  911     FORMAT(///////,' ***** EXPERIMENTAL SPHERE DATA CORRECTED
         1FOR RANGE *****')
  912     FORMAT(////'$','ENTER LOGICAL UNIT NUMBER FOR OUTPUT (7->
         1TERMINAL)  ')
  913     FORMAT(////,' CALCULATED RANGE TO THE TARGET= ',1PG15.7,
         1  METERS')
  914     FORMAT(///,' ENTER THE RANGE CALCULATION FLAG'/// 1=>DIRECT
         1 MEASUREMENT'/' 2=>FOURIER ANALYSIS '///'$INPUT FLAG   ')
  915     FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR SYSTEM RESPONSE
         1(Y OR N)  ')
  916     FORMAT(////'$PRINT SPHERE DATA CORRECTED FOR RANGE (Y OR N)  ')
  917     FORMAT(///////,' ******** TRANSFER CHARACTERISTIC OF SYSTEM **
         1******')
  919     FORMAT(///////,' ******** SYSTEM CLUTTER *********')
 1000     FORMAT(A1)
          STOP '****** END OF PROGRAM ******'
          END
```

LOCAL VARIABLES, PSECT $DATA, SIZE = 000074 (30 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
A	L*1	000032	AMPLIT	R*4	000042	FREQ	R*4	000052
IND1	I*2	000056	K	I*2	000040	PHASE	R*4	000046
STEP	R*4	000034						

COMMON BLOCK /RANGE1/, SIZE = 000010 (4. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
DIST	R*4	000000	IRFLAG	I*2	000004	IUNIT	I*2	000006

COMMON BLOCK /OBJ   /, SIZE = 004002 (1025. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
OBJA	I*2	000000	OBJP	I*2	002000	NSAMP2	I*2	004000

COMMON BLOCK /SYSTA /, SIZE = 010012 (2053. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
TRANA	I*2	000000	TRANP	I*2	002000	CLUTA	I*2	004000
CLUTP	I*2	006000	FSTART	R*4	010000	FEND	R*4	010004
NPOINT	I*2	010010						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
CLUTA	I*2	SYSTA	004000	002000 (512)	(512)
CLUTP	I*2	SYSTA	006000	002000 (512)	(512)
OBJA	I*2	OBJ	000000	002000 (512)	(512)
OBJP	I*2	OBJ	002000	002000 (512)	(512)
TRANA	I*2	SYSTA	000000	002000 (512)	(512)
TRANP	I*2	SYSTA	002000	002000 (512)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	CLOSE	R*4	CORDAT	R*4	FLOAT	R*4	RANCOR	R*4
RANGE	R*4	SPHDAT	R*4	SWEEP	R*4	SYS2	R*4		

```
FORTRAN IV V02 1-1    FRI 30-NOV-79 00:20 50        PAGE 001
          SUBROUTINE SYS2
C         VERSION 1.0 29-NOV-79
C
C
C         THIS SUBROUTINE WILL READ IN THE SYSTEM RESPONSE FILES
C         AND PLACE THEM IN A COMMON BLOCK TO BE PASSED TO OTHER
C         ROUTINES
C
C
          COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
C
          BYTE C
          INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512),NPOINT
C
          TYPE 900
          TYPE *,'OLD OR NEW DATA (1=>NEW,0=>OLD)'
          ACCEPT *,FLAG
          IF (FLAG) 50,50,10
   10     TYPE *, 'ENTER THE STARTING FREQ IN GHZ:'
          ACCEPT *,FSTART
          TYPE *,'ENTER THE ENDING FREQ IN GHZ:'
          ACCEPT *,FEND
          TYPE *,'ENTER THE NUMBER OF FREQ. POINTS:'
          ACCEPT *,NPOINT
          TYPE *,'ENTER THE NUMBER OF SAMPLES AT EACH FREQ.:'
          ACCEPT *,NSAMP2
          TYPE *,'SET UP REFLECTING PLANE FOR TRANSFER FUNCTION MEASURMENT'
          PAUSE '***** HIT RETURN TO PROCEED *****'
          CALL SWDAT(TRANA,TRANP,FSTART,FEND,NPOINT,NSAMP2)
          TYPE *,'STORE DATA ON DISC (Y OR N)'
          ACCEPT 800,C
          IF (C.EQ.'N') GOTO 300
          TYPE 901
          CALL ASSIGN(12,,-1,'NEW','NC',1,)
          WRITE(12,*) FSTART
          WRITE(12,*) FEND
          WRITE(12,*) NPOINT
          DO 30 K=1,NPOINT
          WRITE(12,*) TRANA(K)
          WRITE(12,*) TRANP(K)
   30     CONTINUE
          CALL CLOSE(12)
          GO TO 300
   50     TYPE 901
          CALL ASSIGN(12,,-1,'OLD','NC',1)
          READ(12,*) FSTART
          READ(12,*) FEND
          READ(12,*) NPOINT
          DO 100 K=1,NPOINT
          READ(12,*) TRANA(K)
          READ(12,*) TRANP(K)
  100     CONTINUE
          CALL CLOSE(12)
  300     RETURN

  800     FORMAT (A1)
  900     FORMAT(//1X,'**** SUBROUTINE SYSINP OBTAINS THE SYSTEM RESPONSE
         1 FILES ****')
  901     FORMAT(//'$','ENTER THE TRANSFER FUNCTION FILE NAME: ')
          END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000030 (12 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
C	L*1	000012	FLAG	R*4	000014	K	I*2	000022
NSAMP2	I*2	000020						

COMMON BLOCK /SYSTA /, SIZE = 010012 (2053 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
TRANA	I*2	000000	TRANP	I*2	002000	CLUTA	I*2	004000
CLUTP	I*2	006000	FSTART	R*4	010000	FEND	R*4	010004
NPOINT	I*2	010010						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
CLUTA	I*2	SYSTA	004000	002000 (512.)	(512)
CLUTP	I*2	SYSTA	006000	002000 (512.)	(512)
TRANA	I*2	SYSTA	000000	002000 (512.)	(512)
TRANP	I*2	SYSTA	002000	002000 (512.)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	CLOSE	R*4	SWDAT	R*4				

```
FORTRAN IVV02.1-1     FRI 30-NOV-79 00:21:16        PAGE 001
0001          SUBROUTINE CORDAT
        C     THIS SUBROUTINE WILL TAKE THE DATA THAT WAS TAKEN FROM
        C     SPHDAT AND CORRECT IT WITH THE DATA FROM SUBROUTINE
        C     SYSINP, WHICH IS THE SYSTEM RESPONSE.
        C
        C     VERSION 1.0 30-NOV-79
0002          COMMON/OBJ/OBJA,OBJP,NSAMP2
0003          COMMON/SYSTA/TRANA,TRANP,CLUTA,CLUTP,FSTART,FEND,NPOINT
        C
        C
0004          INTEGER OBJA(512),OBJP(512),TRANA(512),TRANP(512)
0005          INTEGER CLUTA(512),CLUTP(512),NPOINT,NSAMP2
        C
        C    ************************************************************
        C     SUBTRACT ANTENNA CLUTTER FROM OBJECT DATA. THIS CLUTTER DATA
        C     MUST NOT!!! BE CORRECTED FOR THE SYSTEM TRANSFER FUCTION
        C
        C     THE NEXT STEP IS TO DIVIDE BY THE TRANSFER CHARACTERISTIC
        C     OF THE SYSTEM IN ARRAYS TRANA(AMPLITUDE) AND TRANP(PHASE).
        C
        C    ************************************************************
        C
0006          PI=3.1415926
0007          DEG=PI/180
0008          DO 100 K=1,NPOINT
0009          TDBAMP=FLOAT(TRANA(K))*.05
0010          TRPH=FLOAT(TRANP(K))*.25*DEG
0011          ODBAMP=FLOAT(OBJA(K))*.05
0012          OBJPH=FLOAT(OBJP(K))*.25*DEG
        C
        C    ************************************************************
        C     TDBAMP=>TRANSFER CHARACTERISTIC IN DBM.
        C     TRPH=>PHASE OF TRANSFER CHARACTERISTIC IN RADIANS
        C    ************************************************************
        C
        C    ********* DIVIDE BY TRANSFER CHARACTERISTIC ****************
        C
0013          ADBRES=ODBAMP-TDBAMP
0014          PRES=(OBJPH-TRPH)
0015          IF(PRES.GT.PI)PRES=PRES-2.*PI
0017          IF(PRES.LT.-PI)PRES=PRES+2.*PI
        C
        C    ********* REPLACE DATA INTO INTEGER ARRAY ******************
        C
0019          OBJA(K)=IFIX(20.*ADBRES)
0020          OBJP(K)=IFIX((PRES/DEG)*4.)
0021    100   CONTINUE
0022          RETURN
0023          END

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000066 (   27. WORDS)

NAME    TYPE  OFFSET      NAME    TYPE  OFFSET      NAME    TYPE  OFFSET

ADBRES  R*4   000044      DEG     R*4   000016      K       I*2   000022

OBJPH   R*4   000040      ODBAMP  R*4   000034      PI      R*4   000012

PRES    R*4   000050      TDBAMP  R*4   000024      TRPH    R*4   000030
```

```
FORTRAN IVV02.1-1     FRI 30-NOV-79 10:10:36        PAGE 001
0001          SUBROUTINE SWDAT(OBJA,OBJP,FSTART,FEND,NPOINT,NSAMP2)
        C
        C
        C     THIS SUBROUTINE WILL OBTAIN DATA FOR AN OBJECT OVER THE FREQ
        C     RANGE SET WITH THE NUMBER OF POINTS SPECIFIED.
        C
        C
        C
        C
        C
0002          INTEGER OBJA(512),OBJP(512),NPOINT,NSAMP2
0003          INTEGER TRANA(512),TRANP(512),CLUTA(512),CLUTP(512)
        C
0004          STEP=(FEND-FSTART)/FLOAT(NPOINT)
0005          CALL SWEEP(1,FSTART,1,4)
0006          DO 100 K=1,NPOINT
0007          FREQ=FSTART+FLOAT(K-1)*STEP
0008          CALL SWEEP(1,FREQ,1,4)
0009          CALL PHAMP2(IA,IP,NSAMP2)
0010          OBJA(K)=IA-2048
0011          OBJP(K)=IP-2048
0012    100   CONTINUE
0013          CALL SWEEP(1,FSTART,1,4)
0014          RETURN
0015          END

LOCAL VARIABLES, .PSECT $DATA, SIZE = 010040 ( 2064. WORDS)

NAME    TYPE  OFFSET      NAME    TYPE  OFFSET      NAME    TYPE  OFFSET

FEND    R*4 @ 000006      FREQ    R*4   010026      FSTART  R*4 @ 000004

IA      I*2   010032      IP      I*2   010034      K       I*2   010024

NPOINT  I*2 @ 000010      NSAMP2  I*2 @ 000012      STEP    R*4 * 010020

LOCAL AND COMMON ARRAYS:

NAME    TYPE     SECTION  OFFSET  ------SIZE-----  DIMENSIONS
CLUTA   I*2      $DATA    004014  002000 (  512.)  (512)
CLUTP   I*2      $DATA    006014  002000 (  512.)  (512)
OBJA    I*2    @ $DATA    000000  002000 (  512.)  (512)
OBJP    I*2    @ $DATA    000002  002000 (  512.)  (512)
TRANA   I*2      $DATA    000014  002000 (  512.)  (512)
TRANP   I*2      $DATA    002014  002000 (  512.)  (512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME    TYPE   NAME    TYPE   NAME    TYPE   NAME    TYPE   NAME    TYPE

FLOAT   R*4    PHAMP2  R*4    SWEEP   R*4
```

```
FORTRAN IV      V02 1-1     FRI 24-AUG-79 00:19:19                      PAGE 001
0001            SUBROUTINE PHAMP2(IAMP, IPHASE, NUM)
          C     THIS ROUTINE WILL TAKE NUM READINGS FROM A/D CHANNELS
          C     0 AND 1   0=>PHASE   1=>AMPLITUDE
0002            AMP=0
0003            PHAS=0
0004            DO 5 J=1,200
0005      5     CONTINUE
0006            DO 10 K=1,NUM
0007            IAMP1=IADINP(0,1,)
0008            IPHAS1=IADINP(0,0,)
0009            AMP=AMP+FLOAT(IAMP1)
0010            PHAS=PHAS+FLOAT(IPHAS1)
0011            DO 20 J=1,20
0012      20    CONTINUE
0013      10    CONTINUE
0014            IAMP=IFIX(AMP/FLOAT(NUM))
0015            IPHASE=IFIX(PHAS/FLOAT(NUM))
0016            RETURN
0017            END

FORTRAN IV      STORAGE MAP FOR PROGRAM UNIT PHAMP2
LOCAL VARIABLES,  PSECT $DATA, SIZE = 000050 (   20. WORDS)

NAME    TYPE  OFFSET       NAME    TYPE  OFFSET       NAME   TYPE  OFFSET

AMP     R*4   000006       IAMP    I*2 @ 000000       IAMP1  I*2   000022

IPHASE  I*2 @ 000002       IPHAS1  I*2   000024       J      I*2   000016

K       I*2   000020       NUM     I*2 @ 000004       PHAS   R*4   000012

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME    TYPE  NAME    TYPE  NAME    TYPE  NAME    TYPE  NAME    TYPE

FLOAT   R*4   IADINP  I*2   IFIX    I*2
```

```
FORTRAN IV      V02.1-1     FRI 24-AUG-79 00:18:52                      PAGE 001
0001            SUBROUTINE SWEEP(MODE,FREQ,IBAND,IEEENO)
          C     MODE IS THE SWEEPER MODE 1-9.  MODE 1 IS DESCRETE MODE FOR SETTI
          C     THE CW FREQUENCY.  OTHER MODES ARE OUTLINED IN THE SWEEPER IEEE
          C     MANUAL.
          C
          C     IF MODE=10 THEN THE PROGRAM WILL RESET THE INTERFACE
          C
          C
          C
          C     IBAND:      IF IBAND=4 THEN FULL SWEEP 2-18 GHZ OTHERWISE THE
          C     PROGRAM     WILL COMPUTE THE NECESSARY BAND
          C
          C     INITIALIZE IBAND2 AND MODE1 TO ZERO IN THE MAIN LINE
          C
          C
0002            BYTE CMD(7),MD(3),BND(3)
0003            DATA CMD(7)/"15/,MD(3)/"15/,BND(3)/"15/
0004            DATA CMD(1)/'V'/,CMD(6)/'E'/,MD(1)/'M'/,BND(1)/'B'/
0005            IF (MODE-10) 3,2,3
0006      2     CALL IBIFC
0007            GO TO 2000
0008      3     IF (MODE-MODE1) 5,10,5
0009      5     ENCODE(1,1000,MD(2)) MODE
0010            CALL IBIFC
0011            CALL IBREN
0012            CALL IBSEND(MD,,IEEENO)
0013            DO 8  ITER=1,500              !TIME DELAY TO CHAGE MD 13.3 MS
0014      8     CONTINUE
0015      10    MODE1=MODE
0016            IF (IBAND-4) 25,20,25         !IF IBAND IS EQUAL TO 4 THEN TRANSM
0017      20    IBAND1=4
0018            GO TO 35
0019      25    IF ((FREQ .GE. 2.00 ).AND.(FREQ .LT. 6.05)) IBAND1=1
0021            IF ((FREQ .GE. 6.05 ).AND.(FREQ .LT. 12.4)) IBAND1=2
0023            IF ((FREQ .GE. 12.4 ).AND.(FREQ .LT. 18.0)), IBAND1=3
0025      35    IF (IBAND2-IBAND1) 36,38,36
0026      36    ENCODE(1,1000,BND(2)) IBAND1
0027            CALL IBSEND(BND,,IEEENO)
0028            IBAND2=IBAND1
0029      38    GOTO (40,50,60,70),IBAND1
0030      40    B0=2.00022
0031            B1=4.18734E-04
0032            B2=1.27261E-10
0033            GO TO 80
0034      50    B0=5.99786
0035            B1=6.38009E-04
0036            B2=2.03898E-10
0037            GO TO 80
0038      60    B0=12.0018
0039            B1=5.98325E-04
0040            B2=9.44848E-11
0041            GOTO 80
0042      70    B0=1.99636
0043            B1=1.59929E-03
0044            B2=6.01267E-11

FORTRAN IV      V02.1-1     FRI 24-AUG-79 00:18:52                      PAGE 002
          C
          C     THESE CONSTANTS WERE DERIVED USING PROGRAM CALAB BAS ON
          C     AUG-24-1979
```

```
C
90     IV1=IFIX((-B1+SQRT(B1**2-4*B2*(B0-FREQ)))/(2*B2))
       ENCODE(4,1001,CMD(2)) IV1
       CALL IBSEND(CMD,,IEEENO)
       DO 90 ITER=1,200                 !DELAY OF 5.32 MS TO STEP
90     CONTINUE
1000   FORMAT(I1)
1001   FORMAT(I4)
2000   RETURN
       END
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT SWEEP

LOCAL VARIABLES, PSECT $DATA, SIZE = 000070 (28. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
B0	R*4	000036	B1	R*4	000042	B2	R*4	000046
FREQ	R*4 @	000002	IBAND	I*2 @	000004	IBAND1	I*2	000032
IBAND2	I*2	000034	IEEENO	I*2 @	000006	ITER	I*2	000030
IV1	I*2	000052	MODE	I*2 @	000000	MODE1	I*2	000026

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
BND	L*1	$DATA	000022	000003 (2.)	(3)
CMD	L*1	$DATA	000010	000007 (4.)	(7)
MD	L*1	$DATA	000017	000003 (2.)	(3)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
IBIFC	I*2	IBREN	I*2	IBSEND	I*2	IFIX	I*2	SQRT	R*4

```
10 DIM A(500),B(500),F(500)
20 DIM B$(20)
30 PRINT 'INPUT DATA FILE NAME';
40 INPUT A$
50 PRINT 'DATE: ';DAT$
60 OPEN A$ FOR INPUT AS FILE #1
70 INPUT #1,B$
80 B$=SEG$(B$,5,20)
90 F1=VAL(B$)
100 INPUT #1,F2 \ INPUT #1,N
110 PRINT 'START FREQ GHZ. ';F1;'    STOP FREQ GHZ. ';F2;'    # DATA POINTS';N
120 FOR I=0 TO N-1
130 D=(F2-F1)/N
140 INPUT #1,A
150 A(I)=A*.05
160 INPUT #1,B
170 B(I)=B*.25
180 F(I)=F1+I*D
190 NEXT I
200 F(N-1)=F2
210 REGION('UPPER',1)
220 REGION('LOWER',2)
230 GRAPH('LINES',N,F(),A(),,,1)
240 LABEL('UNDERLINE','AMPLITUDE IN DB',,1)
250 GRAPH('LINES',N,F(),B(),,,2)
260 LABEL('UNDERLINE','PHASE IN DEGREES',,2)
270 LINPUT Z$
280 DISPLAY+CLEAR
290 CLOSE #1
300 GO TO 30
310 END
```

APPENDIX II

```
FORTRAN IVV02 1-1     SUN 21-OCT-79 02:12:32       PAGE 001
        PROGRAM BISCAT
C
        COMMON /SCT/FTHETA,FPSI,PSI
        COMMON SO1,SO2,SC1,SC2,KA,THETA
        COMPLEX SO1,SO2,SC1,SC2,FTHETA,FPSI,F
        REAL*4 KA,MAG(512),ANGLE(512),KAS,KAE,PSI,THETA
        BYTE ANS
        DATA C/2.997925E+10/
C
C
        TYPE *,'ENTER SPHERE RADIUS (A)  (CM.):'
        ACCEPT *,A
        TYPE *,'ENTER STARTING FREQ (GHZ):'
        ACCEPT*,FSTART
        TYPE *,'ENTER ENDING FREQ (GHZ):'
        ACCEPT *,FEND
        WAV=2*3.1415926*(1.0E+9/C)
        KAS=FSTART*WAV*A
        KAE=FEND*WAV*A
        TYPE *,'ENTER SCATTERING ANGLE THETA (DEGREES):'
        ACCEPT *,THETA
        THETA=THETA*3.1415926/180.0
        TYPE *,'ENTER POLARIZATION SCATTERING ANGLE PSI (DEGREES).'
        ACCEPT *,PSI
        PSI=PSI*3.1415926/180.0
        TYPE *,'IN WHICH POLARIZATION CALCULATE FIELD (0=>THETA,1=>PSI).'
        ACCEPT *,IPOL
        TYPE *,'ENTER NUMBER OF POINTS'
        ACCEPT*,NUMPTS
        TYPE *,'ENTER LOGICAL UNIT NUMBER FOR OUTPUT'
        ACCEPT *,IUNIT
        WRITE (IUNIT,800)A,FSTART,KAS,FEND,KAE,NUMPTS,THETA*180/3.1415926
       1,PSI*180/3.1415926
        IF (IPOL.EQ.0) WRITE(IUNIT,810)
        IF (IPOL.EQ.1) WRITE(IUNIT,811)
        WRITE(IUNIT,801)
C
C
        STEPK=(KAE-KAS)/NUMPTS
        FREQ=FSTART
        STEPF=(FEND-FSTART)/NUMPTS
        KA=KAS
        DO 100 I=1,NUMPTS
        N=I
        CALL BSCAT
        IF (IPOL.EQ.0) F=FTHETA
        IF (IPOL.EQ.1) F=FPSI
        AMP=CABS(F)
        REA=REAL(F)
        CPX=AIMAG(F)
        ANG=ATAN2(CPX,REA)*(180/3.1415926)
        MAG(N)=AMP
        ANGLE(N)=ANG
        IF (AMP.EQ.0.0) AMP=1.0E-35

        WRITE (IUNIT,*)N,FREQ,KA,10*ALOG10(AMP),ANG
        FREQ=FREQ+STEPF
        KA=KA+STEPK
 100    CONTINUE
        TYPE *,'STORE DATA FOR DISPLAY (Y OR N) :'
        ACCEPT 700,ANS
        IF (ANS.EQ.'N') GO TO 1000
        TYPE *,'ENTER THE NAME FOR DATA FILE:'
        TYPE *,'
        CALL ASSIGN(20,,-1,'NEW','NC',1,)
        WRITE (20,*)NUMPTS
        WRITE (20,*)FSTART
        WRITE (20,*)FEND
        WRITE (20,*)A
        WRITE (20,*)THETA
        WRITE (20,*)PSI
        WRITE (20,*)IPOL
        DO 200 I=1,NUMPTS
        N=I
        WRITE (20,*)MAG(N)
        WRITE (20,*)ANGLE(N)
 200    CONTINUE
 800    FORMAT(////'      RADIUS=',F15.7//'      FSTART=',F15.7/
       1'      START K*A=',F15.7//'      FEND=',F15.7//'      END K*A=',F15.7
       2//'      NUMPTS=',I7//'      THETA=',F15.7//'      PSI=',F15.7/)
 810    FORMAT(///'     FIELD IN THETA POLARIZATION DIRECTION'////)
 811    FORMAT(///'     FIELD IN PSI POLARIZATION DIRECTION'////)
 801    FORMAT(//75('*')///' POINT #',',' FREQUENCY    ',','     K*A
       1'      AMP. DB     ','      PHASE    '//75('*')/)
 700    FORMAT (A1)
 1000   STOP '+++++ END OF PROGRAM +++++'
        END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 010134 (2094. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
A	R*4	010026	AMP	R*4	010074	ANG	R*4	010110
ANS	L*1	010024	C	R*4	010000	CPX	R*4	010104
F	C*8	010004	FEND	R*4	010036	FREQ	R*4	010060
FSTART	R*4	010032	I	I*2	010070	IPOL	I*2	010046
IUNIT	I*2	010052	KAE	R*4	010020	KAS	R*4	010014
N	I*2	010072	NUMPTS	I*2	010050	REA	R*4	010100
STEPF	R*4	010064	STEPK	R*4	010054	WAV	R*4	010042

COMMON BLOCK /   /, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
SO1	C*8	000000	SO2	C*8	000010	SC1	C*8	000020
SC2	C*8	000030	KA	R*4	000040	THETA	R*4	000044

COMMON BLOCK /SCT /, SIZE = 000024 (10. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
FTHETA	C*8	000000	FPSI	C*8	000010	PSI	R*4	000020

LOCAL AND COMMON ARRAYS:

```
FORTRAN IV    V02.1-1    SUN 21-OCT-79 01:15:59         PAGE 001
0001          SUBROUTINE BSCAT
        C
        C
        C     THIS SUBROUTINE WILL CALL SUBROUTINES BSCAT1-BSCAT4 FOR
        C     THE CALCULATION OF THE BISTATIC SCATTERING OF A
        C     PERFECTLY CONDUCTING SPHERE  IT WILL RETURN THE SCATTERING
        C     COEFFICIENT F AS A FUNCTION OF SCATERING ANGLE THETA AND
        C     ANGLE PSI.
        C     THE SCATERED FIELD AMPLITUDE IN THE THETA AND PSI POLARIZATIONS
        C     ARE FTHETA AND FPSI
        C
0002          COMMON/SCT/FTHETA,FPSI,PSI
0003          COMMON SO1,SO2,SC1,SC2,KA,THETA
        C
        C
0004          COMPLEX SO1,SO2,SC1,SC2,FTHETA,FPSI
0005          COMPLEX B1,B2,B3,B4
0006          REAL*4 KA,THETA,PSI
        C
        C
0007          IF (KA.GT.(.4)) GO TO 100
0009          CALL BSCAT1
0010          FTHETA=COS(PSI)*SC1
0011          FPSI=-SIN(PSI)*SC2
0012          GO TO 1000
0013    100   IF (KA.GT.(1.0)) GO TO 200
0015          CALL BSCAT2
0016          FTHETA=COS(PSI)*SC1
0017          FPSI=-SIN(PSI)*SC2
0018          GO TO 1000
0019    200   IF (KA.GT.(20.0)) GO TO 300
0021          CALL BSCAT3
0022          B1=SO1+SC1
0023          B2=SO2+SC2
0024          FTHETA=COS(PSI)*B1
0025          FPSI=-SIN(PSI)*B2
0026          GO TO 1000
0027    300   CONTINUE
        C
        C     KA>20.0
        C
0028          CALL BSCAT4
0029          FTHETA=COS(PSI)*SC1
0030          FPSI=-SIN(PSI)*SC2
0031   1000   RETURN
0032          END
```

LOCAL VARIABLES. PSECT $DATA, SIZE = 000040 (16. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
B1	C*8	000000	B2	C*8	000010	B3	C*8	000020
B4	C*8	000030						

COMMON BLOCK /   /, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET

```
FORTRAN IV    V02.1-1    SUN 21-OCT-79 01:15:39         PAGE 001
0001          SUBROUTINE BSCAT1
        C
        C     THIS SUBROUTINE CALCULATES S1 AND S2 FOR A PERFECTLY
        C     CONDUCTING SPHERE IN THE RANGE KA < .4 AS A FUNCTION
        C     OF THETA THE BISTATIC SCATTERING ANGLE
        C
        C
0002          COMMON SO1,SO2,SC1,SC2,KA,THETA
0003          COMPLEX SO1,SO2,SC1,SC2
0004          REAL *4 KA,THETA
        C
        C
0005          SC1=KA**3*(.5+COS(THETA))
0006          SC2=KA**3*(.5*COS(THETA)+1.)
0007          RETURN
0008          END
```

COMMON BLOCK /   /, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
SO1	C*8	000000	SO2	C*8	000010	SC1	C*8	000020
SC2	C*8	000030	KA	R*4	000040	THETA	R*4	000044

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
COS	R*4								

```
FORTRAN IVV02 1-1     SUN 21-OCT-79 38:24:50       PAGE 001
0001                SUBROUTINE BSCAT2
          C
          C
          C         THIS PROGRAM WILL CALCULATE THE SCATTERING CONSTANTS
          C         OF A PERFECTLY CONDUCTING SPHERE IN THE RANGE
          C         4<= KA <1.  AS A FUNCTION OF BISTATIC ANGLE THETA
          C         SEE RADAR CROSS-SECTION HANDBOOK  GEORGE T RUCK ED.
          C         PLENUM PRESS 1970.
          C
          C
0002                COMMON SO1, SO2, SC1, SC2, KA, THETA
0003                COMPLEX SO1, SO2, SC1, SC2
0004                REAL KA, THETA
          C
          C
0005                T1=.5+COS(THETA)
          C
0006                T2=(.3-(11.0/45.0)*COS(THETA)+(1.0/12.0)*COS(2*THETA))*KA**2
          C
0007                T3=(1.0/120.0)*((1807.0/70.0)-(2531.0/105.0)*COS(THETA)+
               1(57.0/42.0)*COS(2*THETA)+(1.0/3.0)*COS(3*THETA))*KA**4
          C
0008                T4=KA**6*((1.0/6.0)*(4*COS(THETA)-1)+((1.0/5.0)*(1+2*COS(THETA))
               1*KA**2))
          C
0009                SC1R=KA**3*(T1-T2+T3)
0010                SC1I=T4
0011                SC1=CMPLX(SC1R,SC1I)
          C
          C
          C
0012                C1=.5*COS(THETA)+1
          C
0013                C2=(.3-(23.0/60.0)*COS(THETA)-(1.0/18.0)*COS(2*THETA))*KA**2
          C
0014                C3=(1.0/60.0)*(-(1343.0/105.0)+(3769.0/280.0)*COS(THETA)+
               1(57.0/63.0)*COS(2*THETA)+(1.0/8.0)*COS(3*THETA))*KA**4
          C
0015                C4=KA**6*((1.0/6.0)*(4-COS(THETA))+.2*(COS(THETA)+2)*KA**2)
          C
          C
          C
0016                SC2R=KA**3*(C1+C2+C3)
          C
0017                SC2I=C4
          C
0018                SC2=CMPLX(SC2R,SC2I)
          C
0019                RETURN
0020                END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000110 (36. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
C1	R*4	000030	C2	R*4	000034	C3	R*4	000040
C4	R*4	000044	SC1I	R*4	000024	SC1R	R*4	000020

```
FORTRAN IVV02.1-1                                        PAGE 001
0001                SUBROUTINE BSCAT3
          C
          C         THIS SUBROUTINE FINDS THE SCATTERING COEFFICIENTS SO1,SO2,SC1,SC2
          C         USING  A POLYNOMIAL APPROXIMATION IN THE RESONANCE REGION
          C         FOR A PERFECTLY CONDUCTING SPHERE.  RANGE 1<KA<20.  K=WAVE VECTOR
          C         A=RADIUS OF SPHERE  THETA=BISTATIC SCATTERING ANGLE
          C
0002                COMMON SO1, SO2, SC1, SC2, KA, THETA
0003                COMPLEX SO1, SO2, SC1, SC2
0004                COMPLEX T1, T2, T3, T4, T5, T6, B1, B2, B3, CON
0005                COMPLEX CON1, CON2, CON3, CON4, C1, C2, C3, C4, C5, C6, C7, C9
0006                COMPLEX C11, C12, C13, C14, C15, XT, XTM
0007                COMPLEX CON5, CON6, CON7, CON8, CON9
0008                REAL*4 KA, THETA
0009                CON=(0.0,1.0)
0010                X=KA
0011                X3=X**(1.0/3.0)
0012                XM3=1.0/X3
0013                XM23=X**(-2.0/3.0)
0014                COST2=COS(THETA/2.0)
0015                SINT2=SIN(THETA/2.0)
0016                SINT=SIN(THETA)
0017                COST=COS(THETA)
0018                XT=CON*THETA*X
0019                XTM=-XT
0020                PI=3.1415926
0021                PT=(PI+THETA)
0022                PTM=(PI-THETA)
          C
0023                P1=-2*KA*COST2
0024                T1=(KA/2)*CEXP(CON*P1)
          C
0025                P2=-(1./(2*KA*(COST2**3)))
0026                T2=1.0+CON*P2
          C
0027                T3=(7.0/(4*(KA**2)))*((SINT2**2)/(COST2**6)).
0028                SO1=T1*(T2-T3)
          C
0029                P4=-COST/(2*KA*(COST2**3))
0030                T4=(1.0+CON*P4)
          C
0031                T5=(1.0/(4*KA**2))*((6.0+COST)*(SINT2**2)/
               1(COST2**6))
          C
0032                SO2=T1*(T4+T5)
          C
          C
          C         ************ CALCULATE CREEPING WAVE TERMS ************
          C
          C
0033                X=KA
0034                P1=PI*(X+(1.0/12.0))
0035                B1=CEXP(CON*P1)
0036                B2=-CON*X3*SQRT(X/(2*PI*SINT))
0037                C1=B2*B1
          C
          C
```

```
0038        CON1=(.933508,1.616911)
0039        C2=2.715175+(XM23*CON1)
      C
0040        P1=(.8750/(X*TAN(THETA)))
0041        C3=(1.0-CON*P1)
      C
0042        CON2=(.700283,-.404308)
0043        CON3=(.141774,.081853)
0044        B2=PTM*(X3)*CON2
0045        B3=PTM*(XM3)*CON3
0046        C4=CEXP(XTM-B2+B3)
      C
0047        C5=CON*(1.0+CON*P1)
      C
0048        B2=PT*X3*CON2
0049        B3=PT*XM3*CON3
0050        C6=CEXP(XT-B2+B3)
      C
0051        T1=C2*((C3*C4)-(C5*C6))
      C
      C
0052        CON4=(1.032306,1.788036)
0053        CON5=(2.232697,-1.289048)
0054        CON6=(.141482,.081684)
      C
0055        C7=1.391727+(XM23)*CON4
      C
0056        B2=PTM*X3*CON5
0057        B3=PTM*XM3*CON6
0058        C9=CEXP(XTM-B2-B3)
      C
0059        B2=PT*X3*CON5
0060        B3=PT*XM3*CON6
0061        C11=CEXP(XT-B2-B3)
      C
0062        T2=C7*((C3*C9)-(C5*C11))
      C
0063        CON7=(1.607133,-.927879)
0064        CON8=(.099415,.057397)
      C
0065        C12=.201776/(X*SINT)
      C
0066        B2=PTM*X3*CON7
0067        B3=PTM*XM3*CON8
0068        C13=CEXP(XTM-B2-B3)
      C
0069        B2=PT*X3*CON7
0070        B3=PT*XM3*CON8
0071        C14=CEXP(XT-B2-B3)
      C
0072        T3=C12*(C13-CON*C14)
      C
0073        SC1=C1*(T1+T2+T3)
      C
      C
      C ******** CALCULATE SECOND CREEPING WAVE TERM ************
      C
0074        C1=-C1
      C
0075        P2=.339397/(X*SINT)
      C
0076        T4=P2*(C4-CON*C6)
      C
0077        P2=.173966/(X*SINT)
0078        T5=P2*(C9-CON*C11)
      C
0079        CON9=(.848747,1.470073)
0080        C15=1.614208+XM23*CON9
0081        T6=C15*((C3*C13)-(C5*C14))
      C
      C
0082        SC2=C1*(T4+T5+T6)
      C
      C
0083        RETURN
0084        END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000730 (236. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
B1	C*8	000060	B2	C*8	000070	B3	C*8	000100
CON	C*8	000110	CON1	C*8	000120	CON2	C*8	000130
CON3	C*8	000140	CON4	C*8	000150	CON5	C*8	000350
CON6	C*8	000360	CON7	C*8	000370	CON8	C*8	000400
CON9	C*8	000410	COST	R*4	000454	COST2	R*4	000440
C1	C*8	000160	C11	C*8	000260	C12	C*8	000270
C13	C*8	000300	C14	C*8	000310	C15	C*8	000320
C2	C*8	000170	C3	C*8	000200	C4	C*8	000210
C5	C*8	000220	C6	C*8	000230	C7	C*8	000240
C9	C*8	000250	PI	R*4	000460	PT	R*4	000464
PTM	R*4	000470	P1	R*4	000474	P2	R*4	000500
P4	R*4	000504	SINT	R*4	000450	SINT2	R*4	000444
T1	C*8	000000	T2	C*8	000010	T3	C*8	000020
T4	C*8	000030	T5	C*8	000040	T6	C*8	000050
X	R*4	000420	XM23	R*4	000434	XM3	R*4	000430
XT	C*8	000330	XTM	C*8	000340	X3	R*4	000424

COMMON BLOCK /   /, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
SO1	C*8	000000	SO2	C*8	000010	SC1	C*8	000020
SC2	C*8	000030	KA	R*4	000040	THETA	R*4	000044

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

```
NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE
CEXP   C*8    COS    R*4    SIN    R*4    SQRT   R*4    TAN    R*4
```

```
FORTRAN IVV02 1-1     SUN 21-OCT-79 38:26:12        PAGE 001
0001          SUBROUTINE BSCAT4
       C
       C      THIS SUBPROGRAM WILL CALCULATE BISTATIC SCATTERING
       C      COEFFICIENTS FOR THE PERFECTLY CONDUCTING SPHERE. IN THE
       C      RANGE KA>20
       C
       C
0002          COMMON SO1,SO2,SC1,SC2,KA,THETA
0003          COMPLEX SO1,SO2,SC1,SC2,C1
0004          REAL*4 KA,THETA
       C
       C
0005          P1=2*KA*COS(THETA/2)
0006          C1=CMPLX(0.0,-P1)
0007          SC1=-.5*KA*CEXP(C1)
0008          SC2=SC1
0009          RETURN
0010          END
```

LOCAL VARIABLES. .PSECT $DATA, SIZE = 000024 (10. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
C1	C*8	000000	P1	R*4	000010			

COMMON BLOCK / /, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
SO1	C*8	000000	SO2	C*8	000010	SC1	C*8	000020
SC2	C*8	000030	KA	R*4	000040	THETA	R*4	000044

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
CEXP	C*8	CMPLX	C*8	COS	R*4				

```
FORTRAN IVV02 1-1     THU 18-OCT-79 00:04:05        PAGE 001
0001          PROGRAM SPSCAT
       C
0002          COMMON KA,F
0003          COMPLEX F
0004          REAL*4 KA,MAG(512),ANGLE(512),KAS,KAE
0005          BYTE ANS
0006          DATA C/2.997925E+10/
       C
       C
0007          TYPE *,'ENTER SPHERE RADIUS (A)  (CM.):'
0008          ACCEPT *,A
0009          TYPE *,'ENTER STARTING FREQ (GHZ):'
0010          ACCEPT*,FSTART
0011          TYPE *,'ENTER ENDING FREQ (GHZ):'
0012          ACCEPT *,FEND
0013          WAV=2*3.1415926*(1.0E+9/C)
0014          KAS=FSTART*WAV*A
0015          KAE=FEND*WAV*A
0016          TYPE *,'ENTER NUMBER OF POINTS'
0017          ACCEPT*,NUMPTS
0018          TYPE *,'ENTER LOGICAL UNIT NUMBER FOR OUTPUT'
0019          ACCEPT *,IUNIT
0020          WRITE (IUNIT,800)A,FSTART,KAS,FEND,KAE,NUMPTS
0021          WRITE(IUNIT,801)
       C
       C
0022          STEPK=(KAE-KAS)/NUMPTS
0023          FREQ=FSTART
0024          STEPF=(FEND-FSTART)/NUMPTS
0025          KA=KAS
0026          DO 100 I=1,NUMPTS
0027          N=I
0028          CALL SCAT
0029          AMP=CABS(F)
0030          REA=REAL(F)
0031          CPX=AIMAG(F)
0032          ANG=ATAN2(CPX,REA)*(180/3.1415926)
0033          MAG(N)=AMP
0034          ANGLE(N)=ANG
0035          WRITE (IUNIT,*)N,FREQ,KA,10*ALOG10(AMP),ANG
0036          FREQ=FREQ+STEPF
0037          KA=KA+STEPK
0038   100    CONTINUE
0039          TYPE *,'STORE DATA FOR DISPLAY (Y OR N) :'
0040          ACCEPT 700,ANS
0041          IF (ANS.EQ.'N') GO TO 1000
0043          TYPE *,'ENTER THE NAME FOR DATA FILE:'
0044          TYPE *,'                    '
0045          CALL ASSIGN(20,,-1,'NEW','NC',1,)
0046          WRITE (20,*)NUMPTS
0047          WRITE (20,*)FSTART
0048          WRITE (20,*)FEND
0049          WRITE (20,*)A
0050          DO 200 I=1,NUMPTS

0051          N=I
0052          WRITE (20,*)MAG(N)
0053          WRITE (20,*)ANGLE(N)
```

```
0054   200    CONTINUE
0055   900    FORMAT(////'     RADIUS=',F15.7/'      FSTART=',F15.7/
             1'     START K*A=',F15.7/'      FEND=',F15.7/'      END K*A=',F15.7
             2/'      NUMPTS=',I7////)
0056   801    FORMAT(//75('+')//' POINT #','  FREQUENCY    ','    K*A      ',
             1'     AMP  DB      ','         PHASE     '//75('+')/)
0057   700    FORMAT (A1)
0058   1000   STOP '+++++ END OF PROGRAM +++++'
0059          END
```

```
LOCAL VARIABLES,  PSECT $DATA,  SIZE = 010112 ( 2085. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME    TYPE  OFFSET

A      R*4   010016     AMP    R*4   010062     ANG     R*4   010076

ANS    L*1   010014     C      R*4   010000     CPX     R*4   010072

FEND   R*4   010026     FREQ   R*4   010046     FSTART  R*4   010022

I      I*2   010056     IUNIT  I*2   010040     KAE     R*4   010010

KAS    R*4   010004     N      I*2   010060     NUMPTS  I*2   010036

PEA    R*4   010066     STEPF  R*4   010052     STEPK   R*4   010042

WAV    R*4   010032

COMMON BLOCK /      /,  SIZE = 000014 (     6  WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME    TYPE  OFFSET

KA     R*4   000000     F      C*8   000004

LOCAL AND COMMON ARRAYS:

NAME     TYPE    SECTION  OFFSET   ------SIZE-----  DIMENSIONS
ANGLE    R*4     $DATA    004000   004000 ( 1024. )  (512)
MAG      R*4     $DATA    000000   004000 ( 1024. )  (512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME   TYPE   NAME    TYPE   NAME    TYPE   NAME   TYPE   NAME   TYPE

AIMAG  R*4    ALOG10  R*4    ASSIGN  R*4    ATAN2  R*4    CABS   R*4

REAL   R*4    SCAT    R*4
```

```
FORTRAN IVV02.1-1     THU 18-OCT-79 00:03:33        PAGE 001
0001          SUBROUTINE SCAT
        C
        C
        C     THIS PROGRAM WILL CALCULATE THE SCATTERED FIELD FROM A
        C     PERFECTLY CONDUCTING SPHERE  THIS IS A FAR FIELD
        C     APPROXIMATION  AFTER RADAR CROSS SECTION HANDBOOK
        C     GEORGE T  RUCK EDITOR PLENUM PRESS 1970.  PAGES 146-150
        C
        C     VERSION 1.3 OCT-17-79
        C
        C
0002          COMMON KA,F
0003          COMPLEX F,T1,T2,T3,C1,C2,C3,C4,C5,C6,C7
0004          COMPLEX CON,CON1,CON2,CON3,CON4,B1,B2,FO1,FC1
0005          COMPLEX CON5,CON6,CON7,CON8,CON9
0006          REAL KA
        C
0007          CON=(0.0,1.00)
0008          IF (KA.GT..4) GO TO 100
0010          P1=(3.0/2.0)*(KA)**3
0011          F=CMPLX(P1,0.0)
0012          GO TO 1000
        C
0013   100    IF (KA.GT.(.8)) GO TO 200
0015          P1=(3.0/2.0)*(KA**3.0)*(1-(5.0/54.0)*(KA**2)+(17.0/700.0)*
             1(KA**4)-(6.651923E+06/11.907E+06)*(KA**6))
0016          P2=(1.0/2.0)*(KA**6)*(1+(6.0/5.0)*(KA**2))
0017          F=CMPLX(P1,P2)
0018          GO TO 1000
        C
0019   200    IF (KA.GT.20) GO TO 300
        C     ******* OPTICAL TERM C1 *********
        C
0021          X=KA
0022          B1=CON*(1/(2*X))
0023          B2=CON*(-2*X)
0024          FO1=(X/2)*CEXP(B2)*(1.0-B1)
        C     ******** CREEPING WAVE TERM FC1 ********
        C
0025          X3=KA**(1.0/3.0)
0026          XM3=KA**(-1.0/3.0)
0027          XM23=KA**(-2.0/3.0)
0028          CON1=(.741196,1.283788)
0029          CON2=(2.200002,-1.270172)
0030          CON3=(.445396,.257150)
0031          CON4=(.964654,1.670879)
0032          CON5=(7.014224,-4.049663)
0033          CON6=(.444477,.256619)
0034          CON7=(.799821,1.385598)
0035          CON8=(5.048956,-2.915014)
0036          CON9=(.312321,.180319)
        C
0037          PI=3.1415926
0038          P1=PI*(X-(1.0/6.0))
0039          P1=CON*(P1)
0040          C1=-CON*(X**(4.0/3.0))*CEXP(B1)
0041          C2=1.357588*(CON1*XM23)
```

```
      C2=CEXP((-Y3*CON2)+(XM3*CON3))
      T1=C2*C3
C
      C4=.695964*(CON4*XM23)
      C5=CEXP((-Y3*CON5)-(XM2*CON6))
      T2=C4*C5
C
      C6=.807104*(CON7*XM23)
      C7=CEXP((-Y3*CON8)-(XM2*CON9))
      T3=C6*C7
C
      FC1=C1*(T1+T2-T3)
      F=FO1+FC1
C
      GO TO 1000
300   F1=-2*KA
      B1=CON*(P1)
      F=-(1.0/2.0)*KA*CEXP(B1)
C
1000  RETURN
      END
```

LOCAL VARIABLES. PSECT $DATA. SIZE = 000424 (139 WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
B1	C*8	000170	B2	C*8	000200	CON	C*8	000120
CON1	C*8	000130	CON2	C*8	000140	CON3	C*8	000150
CON4	C*8	000160	CON5	C*8	000230	CON6	C*8	000240
CON7	C*8	000250	CON8	C*8	000260	CON9	C*8	000270
C1	C*8	000030	C2	C*8	000040	C3	C*8	000050
C4	C*8	000060	C5	C*8	000070	C6	C*8	000100
C7	C*8	000110	FC1	C*8	000220	FO1	C*8	000210
PI	R*4	000330	P1	R*4	000300	P2	R*4	000304
T1	C*8	000000	T2	C*8	000010	T3	C*8	000020
X	R*4	000310	XM23	R*4	000324	XM3	R*4	000320
Y3	R*4	000314						

COMMON BLOCK / / , SIZE = 000014 (6. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
KA	R*4	000000	F	C*8	000004			

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
CEXP	C*8	CMPLX	C*8						

FORTRAN IVV02.1-1 WED 02-APR-80 00:02:41 PAGE 001

```
      PROGRAM ANTPAT
C
C     AUTHOR C. WERNER 6-MAR-80
C
C     THIS PROGRAM WILL MEASURE THE PATTERN OF AN ANTENNA USING
C     A STEPPER MOTOR CONTROLLED TURNTABLE AND THE HEWLETT-PACKARD
C    8620C MICROWAVE SWEEPER AND 8410B NETWORK ANALYZER IN THE
C     RANGE OF 2-18 GHZ.
C
C
      INTEGER AMP(512),PHA(512)
      BYTE STRING
C
C
      TYPE *,'****** ANTENNA PATTERN MEASUREMENT SYSTEM *******'
      TYPE *,
      TYPE *,'OLD OR NEW DATA? (0=>OLD 1=>NEW)'
      ACCEPT *,IFLAG
      IF(IFLAG.EQ.0)GO TO 500
      TYPE *,'ENTER THE FREQUENCY OF OPERATION IN GHZ:'
      ACCEPT *,FOPT
      TYPE *,'ENTER THE NUMBER OF DATA POINTS:'
      ACCEPT *,N
      TYPE *,'ENTER THE NUMBER OF SAMPLES/DATA POINT:'
      ACCEPT*,NSAMP
      TYPE *,'ENTER THE ANTENNA SWEEP IN DEGREES:'
      ACCEPT *,ANGLE
      TYPE *,'ENTER THE FILENAME FOR THE DATA:'
      TYPE*,
      CALL ASSIGN(15,,-1,'NEW','NC',1,)
      TYPE *,'***** IS THE ANTENNA POSITIONED ? *****'
      PAUSE '***** HIT RETURN TO CONTINUE *****'
      THETA=ANGLE*3.1415926/180.0
      DTHETA=THETA/(N-1)
      A=0.0
      CALL SWEEP(1,FOPT,1,4)
      CALL STEP2(THETA/2.0,1)
      DO 100 I=1,N
      INDEX=I
      CALL PHAMP2(IA,IP,NSAMP)
      AMP(INDEX)=IA-2048
      PHA(INDEX)=IP-2048
      CALL STEP2(DTHETA,0)
100   CONTINUE
      CALL STEP2(THETA/2.0,1)
      WRITE(15,*)FOPT
      WRITE(15,*)ANGLE
      WRITE(15,*)N
      WRITE(15,*)NSAMP
      DO 200 J=1,N
      WRITE(15,*)AMP(J)
      WRITE(15,*)PHA(J)
200   CONTINUE
      CALL SWEEP(10,FOPT,1,4)

      GO TO 700
500   TYPE *,'ENTER FILENAME FOR DATA:'
```

```
      TYPE *,
      CALL ASSIGN(15,,-1,'OLD','NC',1)
      READ(15,*)FOPT
      READ(15,*)ANGLE
      READ(15,*)N
      READ(15,*)NSAMP
      DO 600 J=1,N
      READ(15,*)AMP(J)
      READ(15,*)PHA(J)
600   CONTINUE
700   TYPE *,'PRINT DATA? (Y/N)'
      ACCEPT 992,STRING
      IF(STRING.EQ.'Y')GO TO 800
      GO TO 900
800   TYPE *,'ENTER THE LOGIC UNIT NUMBER FOR OUTPUT'
      ACCEPT *,IUNIT
      WRITE(IUNIT,*)'******* ANTENNNA PATTERN *******'
      WRITE(IUNIT,*)
      WRITE(IUNIT,*)'FREQUENCY GHZ   ',FOPT
      WRITE(IUNIT,*)'PATTERN SWEEP DEG.  ',ANGLE
      WRITE(IUNIT,*)'NUMBER OF POINTS.  ',N
      WRITE(IUNIT,*)'SAMPLES/POINT.  ',NSAMP
      WRITE(IUNIT,*)
      WRITE(IUNIT,990)
      WRITE(IUNIT,*)'POINT #  ANGLE(DEG)   AMPLITUDE(DB)   PHASE(DEG)'
      WRITE(IUNIT,990)
      DO 850 J=1,N
      ANG1=(-ANGLE/2.0)+(ANGLE/(N-1))*(J-1)
      WRITE(IUNIT,991)J,ANG1,AMP(J)*.05,PHA(J)*.25
850   CONTINUE
900   CALL CLOSE(15)
990   FORMAT(60('*'))
991   FORMAT(1X,I6,3X,F7.2,6X,F7.2,10X,F7.2)
992   FORMAT(A1)
      STOP '***** END OF PROGRAM *****'
      END
```

LOCAL VARIABLES, PSECT $DATA, SIZE = 004114 (1062. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
A	R*4	004044	ANGLE	R*4	004030	ANG1	R*4	004064
DTHETA	R*4	004040	FOPT	R*4	004020	I	I*2	004050
IA	I*2	004054	IFLAG	I*2	004016	INDEX	I*2	004052
IP	I*2	004056	IUNIT	I*2	004062	J	I*2	004060
N	I*2	004024	NSAMP	I*2	004026	STRING	L*1	004014
THETA	R*4	004034						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
AMP	I*2	$DATA	000000	002000 (512.)	(512)
PHA	I*2	$DATA	002000	002000 (512.)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE


```
      PROGRAM CYLIN
C
C     AUTHOR C. WERNER FEB 19,1980
C
C
C     THIS PROGRAM WILL GENERATE THE DATA FOR A SWEPT FREQUENCY
C     HOLOGRAM  FOR TWO CYLINDERS OF INFINITE LENGTH.
C
C
      INTEGER SYSA(512),SYSP(512),TARA(512),TARP(512)
      BYTE NAME(20)
      REAL L,KSTEP,KSTART,K1
C
C
      TYPE *,'******* CYLINDER SIMULATION ********'
      TYPE *,'ENTER CYLINDER RADIUS IN CM.:'
      ACCEPT *,A
      TYPE *,'ENTER THE DISTANCE BETWEEN THE CYLINDERS IN CM.:'
      ACCEPT *,L
      TYPE *,'ENTER THE SWEEP START FREQUENCY IN GHZ:'
      ACCEPT *,FBEGIN
      TYPE *,'ENTER THE SWEEP ENDING FREQUENCY IN GHZ:'
      ACCEPT *,FSTOP
      TYPE*,'ENTER THE NUMBER OF LINES IN THE HOLOGRAM:'
      ACCEPT *,NLINES
      TYPE *,'ENTER THE ANGULAR SWEEP FOR THE HOLOGRAM IN DEGREES'
      ACCEPT *,THETA
      TYPE *,'ENTER THE NUMBER OF POINTS PER LINE'
      ACCEPT *,NPTS
C
C
      TYPE *,'ENTER FILENAME FOR DATA'
      TYPE *,'                   '
      CALL GTLIN(NAME,'?')
      OPEN(UNIT=15,NAME=NAME,TYPE='NEW',ACCESS='SEQUENTIAL',
     1FORM='UNFORMATTED')
      WRITE (15) FBEGIN,FSTOP,NLINES,THETA,NPTS
      DTHETA=(THETA/NLINES)*(3.1415926/180.0)
      KSTEP=((FSTOP-FBEGIN)/NPTS)*(2*3.1415926/2.997E+1)
      KSTART=2*3.1415926*FBEGIN/2.997E+1
      DO 400 K=1,NLINES
      ANGLE=(K-1)*DTHETA
      STHETA=SIN(ANGLE)
      DO 200 J=1,NPTS
      K1=KSTEP*(J-1)+KSTART
      SIG=COS(2*K1*A)*COS(K1*L*STHETA)
      IVAL=IFIX(200*SIG)
      WRITE(15)IVAL
200   CONTINUE
400   CONTINUE
      CLOSE(UNIT=15)
      STOP '**** END PROGRAM ****'
      END
```

LOCAL VARIABLES, PSECT $DATA, SIZE = 010136 (2095. WORDS)

```
FORTRAN IV V02.1-1    THU 21-FEB-80 05:03:15       PAGE 001
0001        PROGRAM CVEXP
      C
      C
      C     AUTHOR C  WERNER 21-AUG-80
      C
      C
      C     THIS PROGRAM WILL FIND THE FREQUENCY SWEPT HOLOGRAM OF
      C     A TARGET  WITH VIRTICAL SYMMETRY. THE FREQUENCY RANGE
      C     WILL BE BETWEEN FBEGIN AND FSTOP WITH NPTS FREQUENCY PTS.
      C     THE ANGLE RANGE WILL BE THETA WITH NLINES IN THAT ANGULAR
      C     SWEEP   THE REAL PART OF THE SCATTERED FIELD WILL BE SCALED
      C     FOR DISPLAY BY PROGRAM CDISP.  THE TARGET WILL BE CORRECTED
      C     FOR SYSTEM RESPOSE AND RANGE BY USE OF A REFERENCE TARGET
      C
      C
0002        INTEGER REFA(128),REFP(128),TARA(128),TARP(128)
0003        BYTE NAME(20)
      C
      C
0004        TYPE *,'******** 2D FREQUENCY SWEPT HOLOGRAM *************'
0005        TYPE *,'ENTER STARTING FREQUENCY GHZ:'
0006        ACCEPT *,FBEGIN
0007        TYPE *,'ENTER ENDING FREQUENCY GHZ:'
0008        ACCEPT *,FSTOP
0009        TYPE *,'ENTER THE NUMBER OF FREQUENCY POINTS (<128):'
0010        ACCEPT *,NPTS
0011        TYPE *,'ENTER ANGULAR SWEEP IN DEGREES:'
0012        ACCEPT *,THETA
0013        TYPE *,'ENTER THE NUMBER OF LINES:'
0014        ACCEPT *,NLINES
0015        TYPE *,'ENTER THE NUMBER OF SAMPLES/FREQUENCY POINT:'
0016        ACCEPT *,NSAMP
0017        TYPE *,'ENTER THE NAME OF THE FILE FOR DATA STORAGE:'
0018        TYPE *,'     '
0019        CALL GTLIN(NAME,'?')
0020        OPEN(UNIT=15,NAME=NAME,TYPE='NEW',ACCESS='SEQUENTIAL',
           1FORM='UNFORMATTED')
0021        WRITE(15) FBEGIN,FSTOP,NLINES,THETA,NPTS
0022        DTHETA=(THETA/NLINES)*(3.141526/180.)
      C
      C     GET SYSTEM RESPONSE
      C
0023        TYPE *,'**** PLACE REFERENCE TARGET IN THE FIELD ****'
0024        PAUSE '**** HIT RETURN TO CONTINUE ****'
0025        CALL SWDAT(REFA,REFP,FBEGIN,FSTOP,NPTS,NSAMP)
      C
      C     GET SCALE FACTOR FOR DISPLAY
      C
0026        TYPE *,'**** PLACE IMAGE TARGET IN THE FIELD ****'
0027        PAUSE '**** HIT RETURN TO CONTINUE ****'
0028        CALL SWDAT(TARA,TARP,FBEGIN,FSTOP,NPTS,NSAMP)
0029        RADC=.25*3.1415926/180.05
0030        AMP=0.0
0031        DO 10 K=1,NPTS

0032        TARA(K)=TARA(K)-REFA(K)
0033        TARP(K)=TARP(K)-REFP(K)
0034        IF(TARP(K).GT.720) TARP(K)=TARP(K)-1440
0036        IF(TARP(K).LT.-720) TARP(K)=TARP(K)+1440
0038        AMP=AMP+(TARA(K)*.05)
0039  10    CONTINUE
0040        AMP=AMP/NPTS
0041        TYPE *,'AVERAGE AMPLITUDE IN DB:',AMP
0042        TYPE *,'ENTER DYNAMIC RANGE FOR DISPLAY IN DB:'
0043        ACCEPT *,DBNORM
0044        AMMAX=(DBNORM/2)
0045        AMMIN=-AMMAX
0046        AMAX=10.0**(AMMAX/10.0)
0047        AMIN=10.0**(AMMIN/10.0)
0048        TYPE *,'AMAX=',AMAX,'    AMIN=',AMIN
0049        SCALE=(200.0*(2.0**.5))/(AMAX-AMIN)
0050        TYPE *,'SCALE FACTOR FOR DATA=',SCALE
      C
      C     COLLECT HOLOGRAM DATA
      C
0051        DO 500 J=1,NLINES
0052        CALL SWDAT(TARA,TARP,FBEGIN,FSTOP,NPTS,NSAMP)
0053        DO 100 K=1,NPTS
0054        TARA(K)=TARA(K)-REFA(K)
0055        TARP(K)=TARP(K)-REFP(K)
0056        IF(TARP(K).GT.720) TARP(K)=TARP(K)-1440
0058        IF (TARP(K).LT.-720) TARP(K)=TARP(K)+1440
0060        RNORM=10.0**(((TARA(K)*.05)-AMP)/10.0)*COS(TARP(K)*RADC)
0061        IZ=IFIX(RNORM*SCALE)
0062        TYPE *,K,IZ
0063        WRITE(15) IZ
0064  100   CONTINUE
0065        CALL STEP2(DTHETA,0)
0066  500   CONTINUE
0067        CLOSE(UNIT=15)
0068        STOP '**** END OF PROGRAM *****'
0069        END
```

LOCAL VARIABLES, .PSECT $DATA, SIZE = 002154 (566. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
AMAX	R*4	002110	AMIN	R*4	002114	AMMAX	R*4	002100
AMMIN	R*4	002104	AMP	R*4	002066	DBNORM	R*4	002074
DTHETA	R*4	002056	FBEGIN	R*4	002034	FSTOP	R*4	002040
IZ	I*2	002132	J	I*2	002124	K	I*2	002072
NLINES	I*2	002052	NPTS	I*2	002044	NSAMP	I*2	002054
RADC	R*4	002062	RNORM	R*4	002126	SCALE	R*4	002120
THETA	R*4	002046						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
NAME	L*1	$DATA	002000	000024 (10.)	(20)
REFA	I*2	$DATA	000000	000400 (128.)	(128)
REFP	I*2	$DATA	000400	000400 (128.)	(128)
TARA	I*2	$DATA	001000	000400 (128.)	(128)
TARP	I*2	$DATA	001400	000400 (128.)	(128)

```
FORTRAN IVV02 1-1     SAT 23-FEB-80 01:31:06        PAGE 001
          PROGRAM CDISP
      C
      C   AUTHOR C. WERNER 19-FEB-80
      C
      C
          COMMON/DISPL/IZ,IZINIT,NPTS,IXBEG,IYBEG,ILEN,THETA
          INTEGER IZ(512),Z(8192)
          BYTE A,NAME(20)
          DATA PI/3.1415926/
      C
      C
          TYPE *,'******* 2D HOLOGRAM DISPLAY **********'
    5     TYPE *,'ENTER THE DATA FILENAME:'
          TYPE *,'           '
          CALL GTLIN(NAME,'?')
          OPEN(UNIT=15,NAME=NAME,TYPE='OLD',ACCESS='SEQUENTIAL',
         1FORM='UNFORMATTED')
          READ(15)FSTART,FEND,NLINES,ANGLE,NPTS
          TYPE *,'FREQUENCY GHZ.  (START):',FSTART
          TYPE *,'FREQUENCY GHZ.  (END)  :',FEND
          TYPE *,'NUMBER OF LINES:',NLINES,'POINTS/LINE:',NPTS
          TYPE *,'SWEEP ANGLE DEG.  :',ANGLE
          NPOINT=NLINES*NPTS
          DO 10 J=1,NPOINT
          READ(15)Z(J)
   10     CONTINUE
      C
   15     TYPE *,'LOG COMPRESSION  (Y OR N):'
          ACCEPT 1000,A
          IF(A.EQ.'Y') GO TO 25
          TYPE *,'ENTER CONTRAST SCALE FACTOR:'
          ACCEPT *,SCALF
          SCALF=SCALF*.5
          DO 20 J=1,NPOINT
          Z(J)=IFIX(SCALF*Z(J))
          IF (Z(J).GT.100)Z(J)=100
          IF (Z(J).LT.-100)Z(J)=-100
   20     CONTINUE
          GO TO 30
   25     TYPE *,'ENTER LOG COMPRESSION SCALE FACTOR:'
          ACCEPT *,SCALL
          DO 28 J=1,NPOINT
          IF(Z(J).LT.0)Z(J)=IFIX(-(100.0*ALOG10(1.0-SCALL*Z(J)/10.0)))
          IF(Z(J).GE.0)Z(J)=IFIX(100.0*ALOG10(1.0+SCALL*Z(J)/10.0))
   28     CONTINUE
   30     TYPE *,'ENTER THE INITIAL Z VALUE (500-1000)'
          ACCEPT *,IZINIT
          TYPE *,'ENTER THE STARTING X POSITION (0.0-1.0) '
          ACCEPT *,XSTART
          IXS=IFIX(XSTART*4096)
          TYPE *,'ENTER THE START Y POSITION (0.0-1.0): '
          ACCEPT *,YSTART
          IYS=IFIX(YSTART*4096)
          CALL IDISP(IXS,IYS,IZINIT)

          TYPE *,'POSITION AND INTENSITY CORRECT (Y OR N): '
          ACCEPT 1000,A
          IF (A.EQ.'N') GO TO 30
          TYPE *,'ENTER THE LENGTH OF THE LINE (0-1000): '
          ACCEPT *,ILEN
          PAUSE 'HIT RETURN TO CONTINUE :'
          DTHETA=ANGLE*PI/(FLOAT(NLINES)*180)
          DFREQ=FEND-FSTART
          ILENS=IFIX(ILEN*(FSTART/DFREQ))
          DO 400 J=1,NLINES
          THETA=(J-1)*DTHETA
          IXBEG=IXS+IFIX(ILENS*COS(THETA))
          IYBEG=IYS+IFIX(ILENS*SIN(THETA))
          DO 300 INDEX=1,NPTS
          IZ(INDEX)=Z((J-1)*NPTS+INDEX)
  300     CONTINUE
          CALL LINDSP
  400     CONTINUE
          CALL IDISP(IXS,IYS,IZINIT)
          TYPE *,'DISPLAY SAME DATA AGAIN (Y OR N) : '
          ACCEPT 1000,A
          IF (A.EQ.'Y') GO TO 30
          TYPE *,'RESCALE DATA (Y OR N):'
          ACCEPT 1000,A
          IF (A.EQ.'Y') GO TO 15
          CALL CLOSE(15)
          TYPE *,'DISPLAY A NEW FILE (Y OR N) : '
          ACCEPT 1000,A
          IF (A.EQ.'Y') GO TO 5
 1000     FORMAT (A1)
          STOP '****** END OF DISPLAY PROGRAM *******'
          END

LOCAL VARIABLES,  PSECT $DATA,  SIZE = 040206 ( 8259. WORDS)

NAME    TYPE  OFFSET     NAME    TYPE  OFFSET     NAME    TYPE  OFFSET

A       L*1   040040     ANGLE   R*4   040054     DFREQ   R*4   040114

DTHETA  R*4   040110     FEND    R*4   040046     FSTART  R*4   040042

ILENS   I*2   040120     INDEX   I*2   040122     IXS     I*2   040100

IYS     I*2   040106     J       I*2   040062     NLINES  I*2   040052

NPOINT  I*2   040060     PI      R*4   040024     SCALF   R*4   040064

SCALL   R*4   040070     XSTART  R*4   040074     YSTART  R*4   040102


COMMON BLOCK /DISPL /,  SIZE = 002016 (  519. WORDS)

NAME    TYPE  OFFSET     NAME    TYPE  OFFSET     NAME    TYPE  OFFSET

IZ      I*2   000000     IZINIT  I*2   002000     NPTS    I*2   002002

IXBEG   I*2   002004     IYBEG   I*2   002006     ILEN    I*2   002010

THETA   R*4   002012

LOCAL AND COMMON ARRAYS:

NAME     TYPE   SECTION  OFFSET   ------SIZE-----  DIMENSIONS
IZ       I*2    DISPL    000000   002000 (  512. ) (512)
```

```
FORTRAN IV      V02 1-1     WED 22-AUG-79 13:02:43                PAGE 001
0001          SUBROUTINE LINDSP
        C
        C     THIS SUBROUTINE WILL DISPLAY A LINE OF DATA
        C     UP TO 512 POINTS LONG.
        C
0002          COMMON/DISPL/IZ,IZINIT,NPTS,IXBEG,IYBEG,ILEN,THETA
0003          INTEGER IZ(512)
        C
        C
0004          COSV=COS(THETA)
0005          SINV=SIN(THETA)
0006          DX=ILEN*COSV/NPTS
0007          DY=ILEN*SINV/NPTS
0008          X=FLOAT(IXBEG)
0009          Y=FLOAT(IYBEG)
0010          DO 100 K=1,NPTS
0011          X=X+DX
0012          Y=Y+DY
0013          IX=IFIX(X)
0014          IY=IFIX(Y)
0015          IZVAL=IZ(K)+IZINIT
0016          CALL IDISP(IX,IY,IZVAL)
0017   100    CONTINUE
0018          CALL IDISP(IXBEG,IYBEG,0)
0019          RETURN
0020          END
```

FORTRAN IV   STORAGE MAP FOR PROGRAM UNIT LINDSP

LOCAL VARIABLES, PSECT $DATA, SIZE = 000056 (23. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
COSV	R*4	000004	DX	R*4	000014	DY	R*4	000020
IX	I*2	000036	IY	I*2	000040	IZVAL	I*2	000042
K	I*2	000034	SINV	R*4	000010	X	R*4	000024
Y	R*4	000030						

COMMON BLOCK /DISPL /, SIZE = 002016 (519. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IZ	I*2	000000	IZINIT	I*2	002000	NPTS	I*2	002002
IXBEG	I*2	002004	IYBEG	I*2	002006	ILEN	I*2	002010
THETA	R*4	002012						

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
IZ	I*2	DISPL	000000	002000 (512)	(512)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

```
FORTRAN IVV02 1-1                                          PAGE 001
0001          SUBROUTINE STEP2(RADROT,NDIR)
        C
        C     AUTHOR C WERNER 21-FEB-80
        C
        C
        C     RADROT= ROTATION IN RADIANS
        C     NDIR= DIRECTION FLAG, 0=>CW 1=>CCW
        C
        C
0002          MCW=1024
0003          MCCW=1536
0004          IWCW=1280
0005          IWCCW=1792
        C
        C
        C     STEPS/RAD=10000/PI
        C
0006          STRD=10000.0/3.14159
0007          ISTEP=IFIX(STRD*RADROT)
0008          IF (NDIR) 10,10,20
0009   10     ION=MCW
0010          IOFF=IWCW
0011          GO TO 22
0012   20     ION=MCCW
0013          IOFF=IWCCW
0014          CALL DOUT(,,IERR,IOFF)
0015   22     DO 25 J=1,200
0016   25     CONTINUE
0017   30     DO 500 K=1,ISTEP
0018          CALL DOUT(,,IERR,ION)
0019          DO 50 J=1,200
0020   50     CONTINUE
0021          CALL DOUT(,,IERR,IOFF)
0022          DO 70 J=1,200
0023   70     CONTINUE
0024   500    CONTINUE
0025          RETURN
0026          END
```

LOCAL VARIABLES, PSECT $DATA, SIZE = 000050 (20. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
IERR	I*2	000026	IOFF	I*2	000024	ION	I*2	000022
ISTEP	I*2	000020	IWCCW	I*2	000012	IWCW	I*2	000010
J	I*2	000030	K	I*2	000032	MCCW	I*2	000006
MCW	I*2	000004	NDIR	I*2 @	000002	RADROT	R*4 @	000000
STRD	R*4	000014						

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS.

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE

DATE
ILME